THE ASIA-PACIFIC ERA: ENVIRONMENTAL CHALLENGES

Honorable Jeremy Harris, Mayor, City and County of Honolulu, Hawai'i

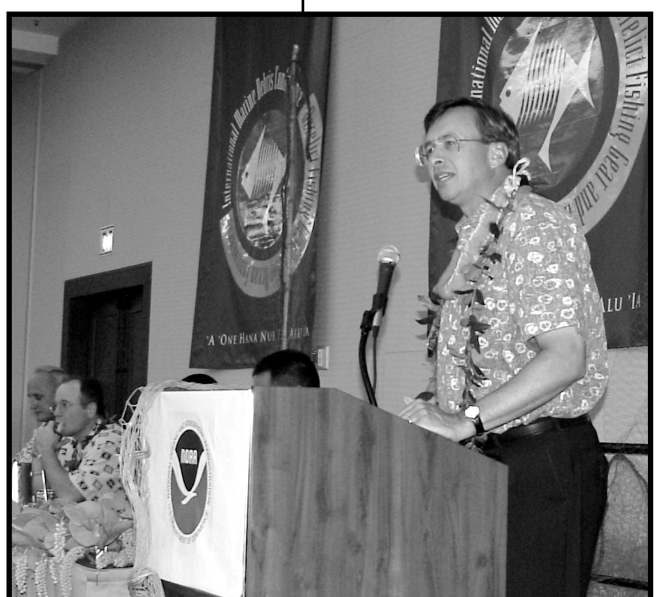
INTRODUCTION

Good morning and aloha.

As Mayor of the City and County of Honolulu, I am honored to welcome our guests from the four corners of the world who are here today as well as our local attendees. You know, when I look at the future of the Asia-Pacific Region, when I look at the challenges that we face as a region, coming to you as a marine biologist and an environmental scientist, I can't help but believe that our environmental challenges are great.

ENVIRONMENTAL CHALLENGES

Apparently, as we enter this new millennium, this new century, it's the environmental challenges that are so important. It's called the Asia-Pacific era that we're now entering, where most of the population growth will be here in our region of the world. And while that may be true, what goes along with that is economic growth, and that is going to result in an enormous series of environmental challenges that could, in fact, threaten the entire planet. And when you look at the kind of consumption and pollution that the United States generated when it went through a period of growth after the Second World War, and you consider that we were only five or six percent of the world's population, and then you look at the growth and increased consumption of natural resources that's going to be occurring in Asia over the next twenty years—it is truly staggering.



Bob Rock, Marine Debris Communications Committee

Honolulu Mayor Jeremy Harris delivers an address on environmental challenges.

As our world becomes more urban and as more people leave rural lifestyles and become part of urban megacities in Asia, the threat to our global climate increases. Air pollution from the consumption of fossil fuels and coal is now being detected even here in Hawai'i. Along with the pollution of our water with improper urban wastewater treatment facilities; the destruction of our ocean ecosystem as a result of over fishing; the destruction of our habitats in some coastal developed areas where we have poor coastal zone management regulations; and the destruction of estuaries—everywhere you look, you see enormous environmental problems on the horizon. One of those environmental problems is the increase in marine debris that is threatening our ocean resources. If there is one commonality throughout all this, it is that these are indeed regional and global problems. Pollution, whether it's air pollution, water pollution, or marine debris, knows no national boundaries.

CONSENSUS BUILDING

If we don't work together, if we aren't forming a consensus on how we're going to attack these regional and global environmental problems, we will not be successful. It's as simple as that. We've got to recognize that the management of our resources has got to transcend regional and national boundaries and interests. They are global interests; they are all of our interests. We are impacted from events in China here in Hawai'i. Our beaches are impacted by the actions of fishing boats in the Central Pacific. We are all one community and we've got to start behaving that way. As an environmental scientist, this is one of things that we have tried to do at the city level—recognize that as a city we have responsibilities for maintaining the quality of our environment here locally, as well as in the Pacific Ocean environment that surrounds us.

We are contributors to ocean debris; from all of the urban waste that runs off our island and all of the plastic wrappers that get thrown into our storm drain system, wash out into our streams, and with heavier rains wash out into the ocean. They litter our reef environment and impact the quality of the ecosystems there. They wash out into the open ocean and create other environmental damage. Two years from now that plastic wrapper that gets thrown out today into the storm drains on Kalakaua Avenue may end up strangling a green sea turtle miles and miles away from our shore.

We bear a responsibility. Locally, what we've tried to do is raise the consciousness of our people so they realize that they themselves are the prime polluters of our ocean. It's not the big industry. It's not some point source where the big pipe is going into the ocean and the valve can just be turned off to solve the problem. We are all responsible; from how we apply pesticides and herbicides to our lawn, to what we throw in that storm drain, to how we handle our household hazardous wastes. We are all responsible for the pollution of our streams and our ocean.

LOCAL EFFORTS

So we created teams of people who are out there working with the community. We have an Adopt-a-Stream Program where community groups, families, and organizations can get together and actually participate in the health and the maintenance of a stream in their community. They work with city crews, cleaning the stream, and removing the debris before it becomes marine debris at the next heavy storm. Of course, the city has stepped up its efforts with high technology to pump out the storm drains and to remove any kind of debris that enters our drainage system before it enters into our streams and our ocean environment. But it takes more than that. It takes an involved electorate and so we're putting ads on the TV; we're encouraging people to get involved; we're enlisting their help in recognizing that they have a role to play. The end result has been, quite frankly, phenomenal; thousands of people are getting involved; groups are adopting streams in their area. We've even started an Adopt-a-Reef Program where people join with us to clean the reefs of material debris that has washed off of our urban environment.

The city also realizes that it has a role in joining with all of you in solving the problem of derelict fishing waste products that end up in our ocean environment. All you have to do is walk on one of our beaches and you will see that we are being impacted. Not only are endangered species being impacted, not only are our waterfowl being impacted, but tourism is being impacted. When tons of waste materials from fishing operations wash up on our beaches, that impacts our very economy here in Hawai'i.

ENVIRONMENTAL AND ECONOMIC POLICY

One of the other lessons to be learned is not only that we're all in this together, but that good environmental policy is good economic policy. That applies to all of these issues on the environment, and it particularly applies to the issue of marine debris. We have a vested interest to play a role in the solution to this problem. And I want to assure all of you that you can count on the city to be an active participant in any of the solutions that are derived from this conference. Our environment is our most important asset, especially here in Hawai'i, and our people recognize it. If we don't work together to protect it and preserve it, we will have very little to turn over to our children and their children.

CONCLUSION

I want to thank you all for being here today. I have issued a proclamation to bring special attention to this conference and to the work that you are doing here. I have proclaimed it "Marine Debris Education Week" in the City and County of Honolulu. I have urged all of our citizens to play an active role in solving the problems of marine debris and to recognize their responsibility in dealing with this regional and global environmental problem. I want to thank you for being here and recognizing that responsibility as well. On behalf of all of our citizens, thank you very much for joining us and good luck with your conference. Aloha.

- Transcribed from a speech given August 7, 2000.

WELCOMING REMARKS

Jim Cook, Chairman, Western Pacific Fishery Management Council, Hawai'i

Good morning. It's wonderful to see so many of our Pacific island neighbors here today and those of you who joined us from various places in the world. My special aloha to members of the fishing industry who have taken time out from their jobs and lawsuits to join us here this morning.

Two years ago, the Western Pacific Regional Fisheries Management Council hosted the first workshop on the population biology of the black-footed albatross, a species that nests in the Northwestern Hawaiian islands. The workshop was part of the council's strategy for dealing with unfortunate interactions between albatross and the longline fisheries.

During the workshop it became abundantly clear that serious though these fisheries interactions were, there were also other important sources of the tross's mortality including the ingestion of lightsticks, disposable lighters, and other plastic marine debris. The Western Pacific Fisheries Management Council subsequently contacted two other regional fisheries management councils in the Pacific to alert them of the albatross problem here in Hawai'i. They also asked the U.S. Department of State to alert Pacific Rim countries about this issue.

Fishermen throughout the world recognize that their livelihood depends on productive oceans. To further this cause, in 1987 we organized the North Pacific Rim Fisheries Conference on Marine Debris held in Kailua-Kona and in 1988 a workshop on fisheries-generated marine debris and derelict fishing gear held in Portland. Many of us had mounted the fisherman's pledge to a clean ocean on our bulkheads and have been involved in a number of other efforts this past decade to prevent and reduce the amount of derelict fishing gear in the ocean. You will undoubtedly hear more about these efforts during the week. But we in the industry also realize that the problem of derelict fishing gear lies beyond the resources of any one nation, agency, organization, or sector. It is a complex and difficult challenge that must be faced cooperatively.

While the magnitude of the problem is challenging, there is cause for optimism. Our gathering here today is one cause. Cooperative efforts between NGOs, industry, and government are key to solving problems in the ocean environment. The industry looks forward to working with all of you today to minimize the impact of fishing gear and to improve the health of the Pacific Ocean environment. Working together we can make a dramatic impact on this problem. Thank you.

- Transcribed from a speech given August 7, 2000.

A MARINE DEBRIS RETROSPECTIVE WITH CHALLENGES FOR THE FUTURE

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INTRODUCTION

Aloha and welcome to Hawai'i, the cradle of the marine debris movement, and to this great opala ohana, Hawaiian for trash get-together. I am very happy to be here and I hope you all are too. Because of my years as Director of NOAA's Marine Debris Program, from 1985-96, your organizers have asked that I provide a brief retrospective of the issue and give you my perception of the challenges you face in tackling fisheries sources of marine debris. Rather than show slides or overheads, my talk today will have a little audience participation. No dancing or anything, just a few questions and some key words for you to jot down.

I assert that Hawai'i is the cradle of the marine debris movement. So my first questions are how do we know if there is a movement or not and how do you know if you are a participant of it? I can help you with the answer. If you go to the beach, or if you go out in your boat, or if you go upcountry and you see trash on the ground and it bothers you, raise your hand. The point is, virtually all of you raised your hand! Certainly a large percentage of the public would have done likewise. Next, if you believe that there is still work to be done to solve the marine debris problem, raise your hand. It looks like all of you again. So we have a multitude of people who perceive a problem and want to work to solve it. In my mind that constitutes a movement.

You cannot have a movement without some history and since people make history, I wish to recognize three of the movement's founders. The first is Dr. Charles Fowler-he is sitting right in front of me-will you stand up a second Chuck? Chuck is the scientist who made the marine debris problem come alive in the early-'80s. His work on northern fur seals in Alaska brought real substance and urgency to the marine debris issue. I also wish to recognize Richard Shimura, Director of the NMFS Hawai'i Laboratory in the '70s and '80s. Richard chaired the first and second International Marine Debris Conferences in 1984 and 1989, both in Honolulu. He edited the reports of these two conferences, creating the information foundation for the movement. Finally I must recognize Ms. Katherine O'Hara, Pollution Program Director for the Center for Marine Conservation (CMC) through the '80s and mid-'90s. Kathy supplied the energy and creativity that transformed the marine debris issue into a broad, international movement. Her work is largely why many of you know and care about marine debris. My point is to show those of you who may be new to the movement that not only are we assembled in the cradle of the marine debris movement, we are standing on the shoulders of some very dedicated individuals, proving that individuals do make a difference!

PREVIOUS MARINE DEBRIS CONFERENCES

By request, I will review some of the principal marine debris conferences and symposia that took place in the last fifteen years or so. I will try to briefly recap the key issues and results of these meetings from my perspective and then focus on the real challenges to you at this the Fourth International Conference on Marine Debris.

The old adage, "What goes around, comes around" couldn't be truer in the marine debris world, especially in the North Pacific. Debris circulates around the ocean and the conferences on this issue seem to have completed their first circuit. This brings me around to 1984 when what I'll call the First International Conference on Marine Debris was convened here in Honolulu.

The title was the Workshop on the Fate and Impacts of Marine Debris (FIMD). The purpose was to bring together fishery biologists, fishery scientists, oceanographers, some population modeling types, and some folks in the fishing industry in an attempt to make an honest assessment of whether marine debris, particularly derelict fishing gear, was a problem worth people's attention. The question was, "Is there enough information to decide whether or not the constituencies represented at the workshop should do something more about marine debris?" Yes, it's trash and it's unsightly, but why do we worry about it in the fisheries context or why should the fishing industry or the fishery manager or the fishery biologist be worried about it? This 1984 Workshop concluded that even though the data were limited there was enough qualitative information to conclude that this was a problem that needed better quantification. This was a problem that needed policy and legal attention as well. The first international conference had several papers addressing the international legal circumstances. They recommended that the U.S. and the other Pacific Rim nations pursue the ratification and implementation of Annex V of the Convention for the Prevention of Pollution from Ships. This became one of the most far-reaching recommendations of the Workshop. Further, the FIMD first recognized and linked the roles of science, education, and mitigation actions in describing the actions necessary to begin to address the marine debris problem. One of the results of the workshop was that the U.S. Congress provided the funding for NOAA's marine debris program in 1985. It was called the Marine Entanglement Research Program (MERP) because it was housed in a research center, but its charge was science, education, and mitigation.

Shortly after the Workshop on Fate and Impact of Marine Debris, Dr. Douglas Wolfe and I organized a one-day workshop on marine debris as part of the Sixth International Ocean Disposal Symposium in Monterey, California. The papers were published as a special edition of a Marine Pollution Bulletin in about late 1987. These collections of papers were written on solution strategies reaching beyond the fishing industry-based problem. This volume also included a paper by the late Dr. Archie Carr, a sea turtle biologist from Florida, about the problems of entanglement and ingestion by sea turtles. This paper detailed the very serious risks marine debris poses for all the sea turtles of the world and led NOAA's program to begin working to protect sea turtles.

The Pacific Rim Fishermen's Conference on Marine Debris was held in Kona, on the Big Island, in 1988. It was sponsored by fishing industry organizations from around the U.S., Canada, Japan, and Korea as well as by NOAA and other government agencies from these countries. The deliberations at this conference attempted to bring some sort of pragmatic treatment to the conundrum faced by the fishing industry and its various segments regarding how one can fish without generating lost fishing gear. The participants freely recognized that they were part of the marine debris problem and initiated the consideration of a wide range of solution strategies, including education programs, gear design, port-based recycling, and gear recovery-all issues highly relevant to today's conference. Further, and get out your pencils to write this down, this meeting recognized the importance of fisheries efforts to "minimize loss and maximize recovery" of fishing gear. Another simple concept that is highly relevant to the current conference charge.

Also in 1988 the White House Domestic Policy Council issued a set of orders to NOAA and the Department of Interior to jointly convene the federal Interagency Task Force on Marine Debris. While it's probably not of much interest to those who do not work for the federal government, that report laid out the rules and the policy prescriptions for how agencies are to behave relative to the purchase of persistent materials, the management of their wastes, the business of recycling, and the enforcement of the laws related to marine debris and solid waste management. Clearly the Task Force recognized the linkage between land-based sources of debris and solid waste management infrastructure. This was an important report, though few people saw it or took the time to read it. It contained a great deal of good advice for federal agencies that turned out to be good advice for industries, including the fishing industry. In that report, get out your pencils now-you need to write this down-it said to "minimize the loss and maximize the recovery of fishing gear." Also, the federal report encouraged the development and broad support of a huge voluntary beach cleanup program. The Center for Marine Conservation took on organizing these and is still carrying on this activity on a huge international basis. The relevant lesson of beach cleanup is, when you pick up somebody else's trash, you will never again throw your own down. Further, data collected during the cleanups provide regular local and regional media attention to the ongoing marine debris problem.

Which brings us to April 1989 and the Second International Conference on Marine Debris in Honolulu, also chaired by Richard Shimura. NOAA did most of the fund raising, organizing, and international solicitation. But Richard chaired the meeting and produced the massive, two-volume report. In my opinion, this second conference was probably the greatest attempt we will ever see to assemble and review the global information available on the marine debris problem. The report became the information base for broadened activity, research, education, and mitigation worldwide. The review of the biological consequences of marine debris in this report is the most thorough to date.

During this period, and largely as a result of the international debates relative to the special area status of the Gulf of Mexico under MARPOL Annex V, a number of U.S. organizations-EPA, NOAA, CMC, Sea Grant-started a series of Caribbean Marine Debris Workshops. In general, the purpose of those workshops was to try to inform the Wider Caribbean islands and coastal states about their natural heritage and the threat to their economy from marine debris, especially from cruise ship activities. These workshops were the beginnings of a collective consciousness in the Caribbean region, particularly island nations, relative to the threat of marine debris and their ability to unite to deal with those problems. These workshops provided impetus that helped attract UN and World Bank assistance for programs to develop port and land-based waste management policy, regulations, and infrastructure in the Wider Caribbean region. By way of these activities the linkage of the marine and land-based waste management systems was recognized as a fundamental challenge in solving the marine debris problem worldwide. There have been five or six of these workshops. The most recent took place in Cozumel, Mexico about two years ago and focused on nautical tourism and port waste management.

The Third International Conference on Marine Debris took place in Miami in April 1994. As part of NOAA's program, I chaired, organized, and edited the book that came out of it. The conference in Miami attempted to integrate across all of the land-based issues, all of the socioeconomic levels from developed to undeveloped, and produce a set of practical recommendations. I don't think we succeeded, but we made real progress given the global state of knowledge and data to solve the marine debris problem. The socioeconomic papers from the third conference truly are first class and the whole volume is worth reading as an update on most marine debris issues. The book from the third conference is the last formal product of NOAA's Marine Debris Program. The Program ended in 1996 and there were no more conferences on marine debris until this one, which I have informally labeled the Fourth International Conference on Marine Debris.

CHALLENGES

Now, I will offer you some of my points of view relative to the challenges before this conference. If you look on the front of the conference brochure, you will find the charge to participants that reads, "Participants will propose an action plan to mitigate damage from derelict fishing gear and reduce impact on marine species and the environment." Your focus is derelict fishing gear. We are not here to talk about land-based sources; we are not here to talk about plastic bags. We are not here to talk about stuff that falls from the sky or washes down the rivers. Derelict fishing gear is a very real problem. It is one of the unsolved problems from twelve years of fairly energetic attention by an awful lot of people on the whole marine debris problem. But first, please bear with me for a few minutes while I summarize what I perceive to be the key challenges to progress on the overall marine debris problem. It's a short list and you may want to jot these down. I will return to derelict fishing gear in a moment.

Land-Based Sources

Worldwide, the majority of persistent wastes entering marine and aquatic systems emanates from land-based sources. We all need to recognize, prior to and during World War II, a huge amount of research and development took place. It resulted in the birth of an entire industry and the source of an entirely new collection of materials with vast, vast, practical implications. These materials are plastics. Because many of them are highly persistent, because they are cheap, because they are easier to use, because they are better than their natural alternatives, and because their uses are expanding, they are accumulating in the environment. I recall that about eight years ago the annual production of virgin plastics was on the order of 50 billion pounds a year, that's billion with a "B" and it is now probably 80 to l00 billion pounds per year. Production depends to some degree on the price of oil. I do not have an estimate of how much of it ends up as waste, but it's a pretty serious proportion, and as Mayor Harris pointed out, the urbanization of the global population results in an ever-increasing dependence on these synthetic materials. As people get further and further away from a rural culture-further and further away from the farm-they get closer to the supermarket and extensive dependence on plastics. I apologize for the digression. My general point is that waste management is not keeping pace with development. This is the largest and most problematic challenge to controlling marine debris.

Port Reception Facilities

Port reception facilities for vessel-generated wastes are lacking worldwide. They are required in most of the developed world, but not everybody uses them and they are not necessarily convenient or cheap to use. Much of the world does not have adequate port-based waste management infrastructure. When ships bring wastes back to port, what happens? It often goes directly or indirectly back into the water.

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National Will

Imagine if you will, a target, the bull's-eye being the focus of national will. Despite the fact that most people think marine debris is a bad thing and should be solved, it is my consistent observation that this issue never occupies the bull's-eye. It rarely ever falls dead center in the attention of nations or the will of a mass of people who have the desire to do something about it. After twelve years of trying to jawbone agencies, countries, industries, and people to work on this issue, you learn that marine debris is not a top priority. So national will is something that needs to be considered. What do you do about it? We didn't solve it before and I don't know what to do about it now. It is one of the most outstanding problems in addressing marine debris.

Derelict Fishing Gear

Finally, in my short list of unfinished business, we come (back) to derelict fishing gear. Consider this, and if you don't agree with these percentages, you can raise your hand and I'll ignore you. It is more or less accepted that 80% of the persistent debris of the ocean environment comes from land-based sources. That means 20% comes from maritime sources. You have cruise ships, transport vessels, military vessels, ferries, and you have fishing boats. For argument's sake let us agree that 10% of the maritime debris comes from fishing boats. That means about 2% of the persistent marine debris in the ocean comes from fishing boats.

Now we look at fishing gear versus other persistent gear that comes from fishing boats. If half of the persistent waste that comes from fishing boats is actually fishing gear, then 1% of the total marine debris is fishing gear. There is another step here. Fishing boats don't throw good fishing gear over the side. When they have waste fishing gear, they have a choice to retain it on board or jettison it illegally-a voluntary contribution to the debris problem. Fishermen also lose their gear in the legal act of fishing-an involuntary contribution to the debris problem. Clearly the voluntary contribution is fully addressed under MARPOL Annex V and its domestic implementing legislation and may consist of of $^1/_2$% of 1% of marine debris. The other $^1/_2$% of marine debris is derelict fishing gear, the target of this conference.

Fishing gear is capital equipment and it's legal to fish. Under the right regulations and circumstances you can go fishing and risk your capital equipment (gear) to catch some fish. If you are right, you make some money. If you are wrong, you may lose your gear and not be able to recover it. It could stay right where it was lost or it could float around in the North Pacific and end up in the Northwestern Hawaiian Islands. I do not mean to minimize the importance of derelict fishing gear as a marine debris problem. It clearly is the most biologically threatening of the debris types. In the North Pacific, where sea turtles, seabirds, corals, and the last monk seals on earth are at risk, it is a high priority problem.

Besides, quite obviously, 100% of the derelict fishing gear in the ocean comes from fishing vessels. Therefore, as a practical reminder, I would like everyone to write these two phrases down, “voluntary sources” and “involuntary sources” of derelict fishing gear. These are two very different problems. The involuntary source problem is really tough. We made very little progress on this during NOAA's twelve-year program.

In considering the approaches for dealing with the involuntary sources of derelict fishing gear, I am reminded of Shirley Laska's work on technical interventions for controlling marine debris. She showed us that we have two distinct options, intervention and remediation. Please jot these terms down as they may help you organize your action plan. Remediation is what you do after the derelict gear has done its damage. For example, the rehabilitation of entangled monk seals or sea turtles is a type of remediation. Intervention is the suite of activities that may reduce or eliminate the threat of damage by marine debris. The options for intervention in the generation and distribution of derelict fishing gear range from changing the risk-taking calculus of fishermen or potential fishermen; engineering harder to lose, easier to recover gear; recycling systems for recovered gear; bounty systems and bonds, etc. to actively gather derelict gear at sea. Choosing when and where it will be efficient to intervene is the greatest challenge you face-it presumes you know the details of fishing gear design and operation, the incentives of fishermen, the hazard profiles of each gear type in each environment, and the legal, economic, and social context of each fishery. As with all truly worthy problems, the devil is in the details.

CONCLUSION

The final challenges are really pretty simple. To illustrate, if your full-time job is to deal with marine debris, please raise your hand. Out of about 200 people gathered at a conference on marine debris, we have just one person whose full time employment is focused on marine debris! Everybody is a member of the movement, but nobody is responsible for making progress—this is a particularly sad state of affairs. Take out your pencils and write down this question, “Whose job is it?” There is no one in Japan, no one in Turkey, no one in Australia. You may want to jot down the corollary question, “Who pays for it?” There is about $38 billion in the Heinz Trust, is there any for marine debris? There is about $6 billion in the Pew Trust, is there any for marine debris? There is $3 trillion or so in the U.S. federal budget that used to include $750,000 for marine debris; it's gone. I repeat, “Who pays?” And the final question we all should ask and answer is “What constitutes success?”

You have chosen to tackle a very real problem. If it were an easy one, we would have solved it years ago. I encourage all of you to actively participate in the conference workshops. Revisiting the issues may help you and questions I asked you to write down. I firmly believe that your work this week and in the future will revitalize the movement and make real progress in tackling derelict fishing gear.

Mahalo, thank you for listening and good luck with the tasks before you.

v Transcribed from a speech given August 7, 2000.

ORIGINS, TYPES, DISTRIBUTION, AND MAGNITUDE OF DERELICT FISHING GEAR

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Prior to beginning my formal presentation, I would like to take a moment to give special recognition to my other marine debris hero here today, besides Captain Terry Rice. He is somebody locally we all know, or know of, because he is the one who is always there removing marine debris, always taking the critical photograph, always remembering to have a video camera handy, always doing the right things. More than anyone else, he helped us identify the marine debris problem in the Northwestern Hawaiian Islands. Since he is generally soft-spoken, certainly modest, and does not frequently come up on stage, I'd like to introduce him to those here who do not know him except by his photographs and videos. He is, of course, Ray Boland. Ray please stand. Everyone, please join me in giving him a hand for his outstanding contributions. Thank you very much.

Intended as an introductory overview, my talk today will instead be a concluding overview describing some of the source fisheries around the Pacific basin, their gear types, and some of the oceanographic mechanisms responsible for the eventual distribution of derelict fishing gear.

BACKGROUND

Prior to the 1950s, most fishing gear was composed of natural fibers and fabrics such as manila, jute, sisal, hemp, cotton, and linen. These natural fibers were highly susceptible to environmental degradation and did not last very long in the marine environment. If they were lost, they generally degraded quickly and therefore did not pose a long-term ecological threat. With the introduction of synthetics to the fishing industry in the late- 1940s and 1950s, this started to change quite rapidly. By 1964, 95% of nets produced in Japan were of synthetic origin, and presently almost all commercial fishing gear is composed of synthetics. One of the principal advantages of synthetics is their high resistance to

environmental degradation. This resistance allows these materials to persist much longer in the marine environment and therefore poses the potential for long-term ecological damages.

Although most of our experience focuses on the impacts and problems of derelict fishing gear found entangled on the coral reefs and beaches of the Northwestern Hawaiian Islands, marine debris and derelict fishing gear pose similar problems throughout the Pacific, and indeed, the global ocean. As with many other areas, the derelict fishing gear found accumulating in the Northwestern Hawaiian Islands rarely originates from local fisheries. In this area, the only fisheries are small-scale bottom-fishing and lobster trapping activities, and pelagic longlining outside a 50 mile protected species zone surrounding all of the islands. Instead, the derelict fishing gear recovered in the Northwestern Hawaiian Islands originates from fisheries throughout the North Pacific Ocean and even the entire Pacific basin. The Northwestern Hawaiian Islands are not unique in this respect. Derelict fishing gear, no matter the location of the source fishery, will accumulate wherever the ocean currents take it. Of the derelict fishing gear found in the Northwestern Hawaiian Islands, surveys over the past four years show that the highest percentages of derelict gear consist of bottom and midwater trawl nets, pelagic and coastal driftnets, set nets and other gillnets, and miscellaneous line. Purse seine, troll, and longline gear is also found but the amounts are generally low.

PACIFIC FISHERIES AND GEAR TYPES

In order to discuss where derelict fishing gear originates, we first describe briefly and simply the types of fishing gears used around the Pacific basin and, in general terms, where the fisheries operate.

Trawling

Bottom trawl fisheries tow or drag large nets over the bottom to capture demersal fish in water depths from very shallow to depths as great as 350 fathoms. These fisheries occur primarily in areas with extensive continental shelves, such as the Bering Sea and much of the nearshore waters off the Pacific coasts of the Americas and the Asian continent. Bottom trawl gear is occasionally lost accidentally as the gear becomes entangled or snagged on the bottom. Since these nets are quite expensive (~$50,000 U.S.), fishermen try to avoid areas likely to foul their gear. Only when bottom trawls are irreparably damaged might a trawler consider purposeful discarding of nets. Midwater trawling uses similar gear, but the tows are conducted above the bottom and target midwater species. These fisheries also occur principally in productive coastal waters of the continental shelves around the Pacific Rim. The risks of loss of midwater gear are significantly decreased since the gear is not intended to encounter the bottom. Both bottom and midwater trawling gear remains attached to the vessel at all times.

Gillnets

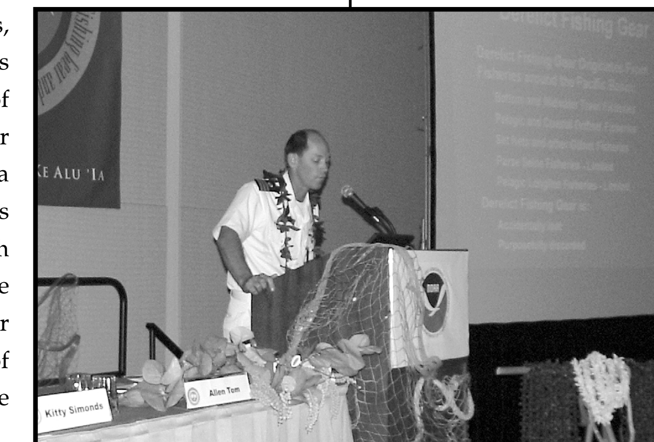
Gillnets of various types are used to entangle fish and other marine species that inadvertently swim or drift into their relatively invisible mesh. Gillnets consist of a vertical curtain of nearly invisible mesh across a waterway. As such, gillnets represent a very efficient, but not very discriminating, fishing gear. This efficiency led to a significant pelagic driftnet fishery upon the high seas of the Pacific Ocean until public concerns over their indiscriminant fishing and high incidental catch rates led to international bans. Data from Japanese, Korean, and Taiwanese driftnet fisheries prior to the bans show that much of this fishery focused on the subtropical and subarctic fronts of the central North Pacific Ocean between the latitudes of 35° N and 45° N. These data show that the large mesh Japanese driftnet fishery occurred right up to the 200 nautical mile U.S. Exclusive Economic Zone surrounding the Northwestern Hawaiian Islands, where high numbers of large (~4,000 lb.) derelict driftnets are found fouled on the coral reefs and beaches. Many of the large pelagic driftnets lost during the heyday of the high seas driftnet fishery of the 1970s and 1980s appear to be still circulating around the ocean gyres. Although there remain reports of continued high seas driftnet fishing, this form of fishing has decreased significantly since international bans went into effect. Since driftnets are set free of their vessels, loss rates were sometimes quite high, particularly in areas with harsh weather or strong current shears. Coastal driftnets and set nets are still frequently used along coastal waters around the Pacific Ocean. Although these smaller nets are easier to keep track of than high seas driftnets, they are nevertheless occasionally lost or fouled upon the bottom.

Troll, Purse Seine, Trap, and Longline Fisheries

Other major fisheries of the Pacific Ocean, such as troll, purse seine, trap, and longline fisheries, appear to make only a relatively small contribution to the derelict fishing gear problem. Troll fisheries tow lines with baited hooks or lures behind small vessels. The amount of gear lost from troll fisheries and the impacts of this lost gear are considered relatively small.

Purse seine fisheries attempt to surround schools of fish, predominantly tunas and other pelagic fishes, with large vertical curtains of the seine net and then close or purse the net around the encircled fish. Although the purse seine fishery is now again very large and expanding throughout much of the tropical Pacific Ocean (after lengthy closures of the fisheries due to concerns about dolphin takes), it is highly unlikely for fishermen to lose this gear since the net remains attached to the vessel throughout the fishing operation and the costs of the nets are very high. It is not unreasonable to assume that derelict purse seine nets or pieces of nets are likely to have been purposely discarded only after significant degradation or damage. In recent years, much of the purse seine fleet in the Pacific has set their nets around floating or moored fish aggregating devices.

Trap fisheries of many different types target lobsters, crabs, fish and other species. Although each trap fishery is different, most consist of setting baited traps or strings of traps along the bottom with surface buoys to mark their position for retrieval. Since trapping is predominantly a bottom fishery utilizing negatively buoyant traps, lost traps generally pose a local ecological threat as contrasted with the other more buoyant gear types that freely drift with the ocean currents when lost. The lines and floats used for gear retrieval, however, are sometimes lost and become a part of the derelict fishing gear more widely distributed around the Pacific Ocean.



Bob Rock, Marine Debris Communications Committee

CDR Rusty Brainard (NMFS) delivers information on the origins of derelict fishing gear.

The large pelagic surface monofilament longline fishery utilizes long lines (10 km-100 km in length) of baited hooks segmented with surface floats or buoys along the line to maintain desired fishing depths of the gear and to mark the location of the line for retrieval. This extensive fishery targets numerous highly migratory species such as tunas and billfish from 40° N to 40° S across the entire Pacific basin from west to east. Although longlining gear is sometimes both lost and discarded, most of the derelict longline gear tends to sink to the abyss, where impacts are poorly known. Lost floats and float lines would, of course, stay at the surface and become part of the floating derelict gear circulating with the ocean currents. Longline fishing gear does not represent a large percentage of the derelict fishing gear found during surveys in the Northwestern Hawaiian Islands.

Summarizing fisheries, there are many different types of fishing gear used throughout the Pacific Ocean. As one might expect, the types of gear most prone to accidental loss, such as bottom trawls and driftnets, are the most common types found during surveys of derelict fishing gear in the Northwestern Hawaiian Islands. In the case of trawl gear, the remote origin is particularly clear since there are no trawl fisheries within thousands of kilometers of the Northwestern Hawaiian Islands. The fact that the most common types of derelict fishing gear found are also the most likely to be lost supports the hypothesis that fishermen, in general, do not want to lose their gear. Fishermen are at sea to earn a living and cannot afford to lose expensive gear. Unfortunately, cost considerations may also be the reason that some fishermen do purposefully discard irreparably damaged gear. Very few harbors around the Pacific basin provide cost-effective means for discarding damaged gear. Some ports do not offer any means for legally discarding gear, particularly large nets. For fishermen barely making financial ends meet, it is not surprising that some might succumb to the temptation to reduce high shoreside disposal costs by discarding worn out nets and gear at sea. One obvious solution to this aspect of the problem would be for coastal states to support port disposal facilities and work to encourage fishermen to dispose of their waste properly.

DISTRIBUTION AND MAGNITUDE

Once lost or discarded, each type of gear poses different ecological threats. Negatively buoyant gear, like traps, longlines, and some weighted or snagged bottom trawls, sink to the bottom and become localized threats. Positively buoyant gear, like trawls, driftnets, and seine nets, are more likely to circulate with the ocean currents and be distributed from the region of their source fishery to regions far removed. On the surface, much of this gear continues to entangle and entrap fish, marine mammals, birds, and other species. At the surface, this derelict gear also poses a serious navigational and safety threat to vessels of all sorts.

There have been numerous methods of estimating amounts and distributions of marine debris and derelict fishing gear over the past two decades. In general, these methods can be simplified into the following categories: visual beach surveys, visual shipboard surveys, shipboard trawl surveys, diving surveys, and aerial and satellite remote sensing reconnaissance.

Beach Surveys

Beach surveys for derelict fishing gear are often a cost-effective way of providing valuable information on the prevalence of derelict fishing gear and for monitoring trends (Ribic et al., 1992). Beach surveys of derelict fishing gear in the Northwestern Hawaiian Islands from 1982 to 1999 were completed in conjunction with studies on entanglement rates of the endangered Hawaiian monk seal and show no decline in the amount of derelict fishing gear on these remote beaches (Henderson, in review). In association with the beach surveys of 1999, 12,500 pounds of derelict fishing gear was removed from the beaches of just two islands of the Northwestern Hawaiian Islands (Donohue, unpublished data). Slip and Burton (1991) reported that derelict fishing gear accounted for 29% of the debris found on the beaches of Macquarie Island in the Southern Ocean, despite the fact that this area does not support a regional fishery. In Australia, derelict fishing gear accounted for 2%-41% of the total debris on beaches (Slater, 1991; Edwards et al., 1992; O'Callaghan, 1993; and see Jones', 1994 review). Derelict fishing gear is also a notable component of beach surveys for marine debris in Mexico (Coe et al., 1996).

Shipboard Surveys

Shipboard sighting surveys for the assessment of marine debris distribution and amount consist of visually inspecting the ocean surface for floating debris. This method is particularly suited for medium to large derelict fishing gear items (see Ribic et al., 1992 and Hess et al., 1999), and requires dedicated or opportunistic vessels, good visibility, and favorable weather. Observers stationed on the flying bridge or other elevated sections of the ship visually search for debris items in strip or line transects. During strip transects, debris

items are counted on the side of a ship within a specified distance, commonly ranging from 50 m (Day and Shaw, 1987; Day et al., 1990a) to 100 m (Dixon and Dixon, 1983). During line transects all debris items visible are counted regardless of their distance from the ship. When the perpendicular distance of the objects to the ship can be accurately measured, the line transect method is preferable (Ribic, 1990; Burnham et al., 1985). Platforms of opportunity are often used as a result of cost constraints, thus the sampling area, height of the observer above the water, ship speed, etc. may not be controlled by the researcher. These factors affect the accuracy of the assessments (Mio and Takehama, 1988; Ribic et al., 1992). Furthermore, as the characteristics of the debris (size, color, buoyancy, and shape) affect its visibility to surveyors, accurate characterization of debris is not readily accomplished (Mio and Takehama, 1988).

Despite these challenges, numerous informative sighting surveys have been completed. Dedicated vessels combined with vessels of opportunity have been used in Pacific-wide surveys conducted by the Fisheries Agency of Japan from 1986 to 1991 (Matsumura and Nasu, 1997). Matsumura and Nasu (1997) reported derelict fishing net density to be relatively higher in the area of 20° to 30° N, 150° to 130° W of the eastern Pacific Ocean. They also noted a high density of derelict fishing nets on the Pacific Ocean side of Japan from 30° to 40° N, 140° to 150° E. The distribution of derelict fishing gear, other than nets, was found to have a wider general distribution, with the greatest densities (greater than 120 pieces per 100 square nautical miles) found from 25° to 35° N, 130° to 180° W. Mio et al. (1990) and Mio and Takehama (1988) previously reported a high-density area of derelict fishing nets northeast of Hawai'i during sighting surveys conducted in 1986. Day and Shaw (1987) also completed a multiple-year study in the Gulf of Alaska in 1984 and 1985. Other baseline studies have been conducted in the North Pacific (Dahlberg and Day, 1985; Ignell, 1985; Jones and Ferrero, 1985; Ignell and Dahlberg, 1986; Day et al., 1990; Shaw, 1990). Additional regional sighting surveys were conducted around the Pribilof Islands in the Bering Sea (Yoshida and Baba, 1985; Baba et al., 1988, 1990).

Trawl Surveys

Shipboard trawl surveys can be used to survey marine debris on the surface of the water or on the seafloor. Neuston-type nets can be used to sample small floating marine debris and larger nets can be deployed to sample debris that has sunk to the benthos (Ribic et al., 1992). The latter are useful for the assessment of medium to large derelict fishing gear items. Trawling techniques mimic those used for fishing, with the net deployed to sample or "catch" debris resting on the seabed (see Ribic et al., 1992). The mesh size of the net used determines the minimum size of debris that may be caught. Trawl sampling studies may be conducted opportunistically in association with commercial, experimental or managed fisheries or with dedicated cruises targeting marine debris. The common occurrence of marine debris in benthic trawls on the continental shelf of the Northeast Gulf of Alaska was reported as early as 1976 (Jewett, 1976). Bering Sea fishing areas were also found to have greater amounts of benthic debris than areas not fished (Feder et al., 1978). More recently, Hess et al. (1999) investigated fishery-related items caught during benthic trawls to survey crab and groundfish resources around Kodiak Island, Alaska. In the three years of their study, fishery-related items comprised 46%, 42%, and 38% of the total benthic debris recovered. Fishery-related debris densities ranged from 4.5-25.0 items/km2. The debris densities reported by Hess et al. (1999) were between those reported by June (1990) for the Eastern Bering Sea (2-7.5 items/km2) and off the Oregon Coast (150 items/km2). Although shipboard trawl surveys have been used most extensively for surveying benthic marine debris, they cannot be employed in very shallow waters, on steep slopes, or in sea canyons.

Diver Surveys

Other methods investigated or proposed to survey benthic marine debris involve submersibles, towed camera systems, and divers. The cost and availability of manned submersibles and remotely operated vehicles (ROVs) have limited their use in marine debris surveys (Ribic et al., 1992). Divers can execute surveys for derelict fishing gear in areas too shallow to employ submersibles or ROVs, and where seabed topography restricts trawl surveys (Ribic et al., 1992). Furthermore, divers can remove derelict fishing gear from the substrate in a surgical fashion, reducing additional environmental damage to reefs during removal. Small vessels towing divers can be deployed from ship platforms at oceanic sites or from land-based laboratories for coastal surveys.

A large-scale project utilizing divers to conduct surveys for, and remove, derelict fishing gear in the Northwestern Hawaiian Islands began with a NMFS pilot study in 1996 (Boland, unpublished data). In 1996 and 1997, diver survey and removal techniques were refined allowing the removal of 10,000 pounds of derelict fishing gear from the shallow coral reefs. In 1998 and 1999, NMFS efforts were significantly expanded by partnering with a consortium of state, federal, and private organizations. The distribution, density, type, and organic fouling of derelict fishing gear were documented using snorkel divers towed in systematic parallel track survey transects behind small boats. Derelict fishing gear is subsequently recovered using small boats and snorkel and scuba divers. To date, over 77,000 pounds of derelict fishing gear has been recovered from the Northwestern Hawaiian Islands through these efforts (Donohue, unpublished data).

ORIGINS, TYPES, DISTRIBUTION, AND MAGNITUDE OF DERELICT FISHING GEAR

Oceanography and the Role of Remote Sensing

Once floating derelict fishing gear enters the ocean, it continues to circulate around the Pacific basin with the ocean currents until it either fouls upon shallow reefs or banks or eventually degrades. Due to the resistance of modern synthetics to degradation, it is believed that some derelict fishing gear continues to circulate with the currents for years or decades. In order to evaluate distributions of marine debris, it is therefore useful to examine the circulation patterns of the upper ocean. Looking at maps of the general circulation of the Pacific Ocean in general navigation or oceanography references, the upper ocean currents seem very simple and predictable. There are large-scale oceanic gyres with clockwise flow around the North Pacific and counterclockwise flow around the South Pacific (figure 1). Various currents around the Pacific are given names and appear to be well known.

In the long-term mean, these current maps are probably nearly correct. However, at shorter and shorter time scales from years to months to days, the motion of the upper ocean is now known to be extremely complex, with many different time and space scales of variability (figure 2). Oceanographers often track upper ocean currents using satellite-tracked drifters. These drifter tracks tell us that any particular piece of marine debris will not follow the mean circulation patterns, but will instead follow a complex trajectory driven by the combined effects of wind-driven currents, wave-driven currents, and thermohaline or density-driven currents. Kubota (1994) utilized a simplified numerical model to track virtual drifters (marine debris) around the North Pacific by computing these three types of currents. He forced the model using monthly climatological conditions (i.e., long-term mean January, February, etc.) of the ocean and atmosphere at relatively large spatial scales. After running the simulation for five years, his model found accumulation of marine debris in the region north of the Hawaiian Archipelago, where shipboard sighting surveys had found the highest accumulations of marine debris.

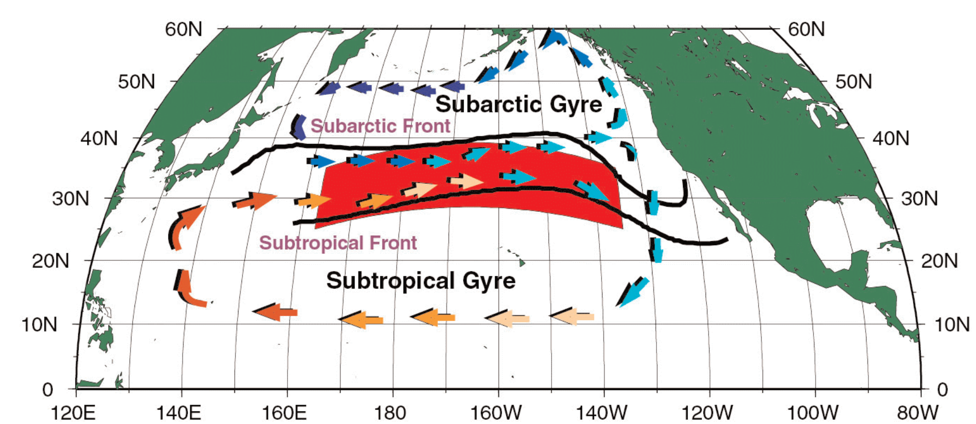


Figure 1
General ocean circulation patterns of the North Pacific

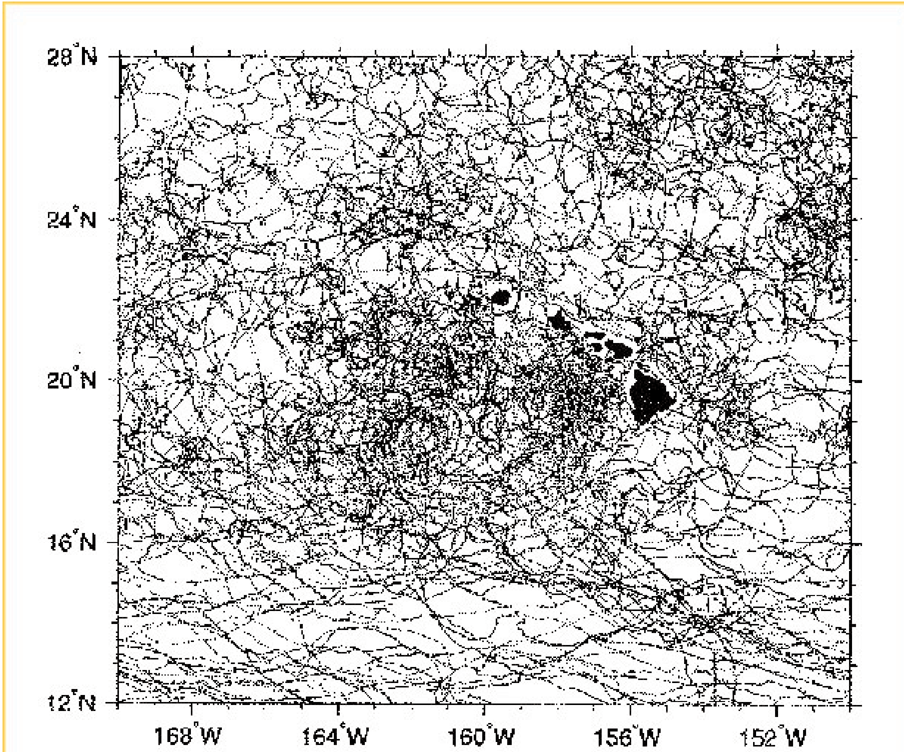


Figure 2
Composite diagram of satellite-tracked surface drifter trajectories around the Hawaiian Islands (Qui et. al, 1997).

More recently, we have been investigating the utility of remote sensing to monitor and assess marine debris. We have been developing methods to apply knowledge of oceanographic processes and use of satellite remote sensing of ocean surface properties to identify and monitor regions where derelict fishing gear and other forms of marine debris would most likely accumulate (Brainard et al., 2000).

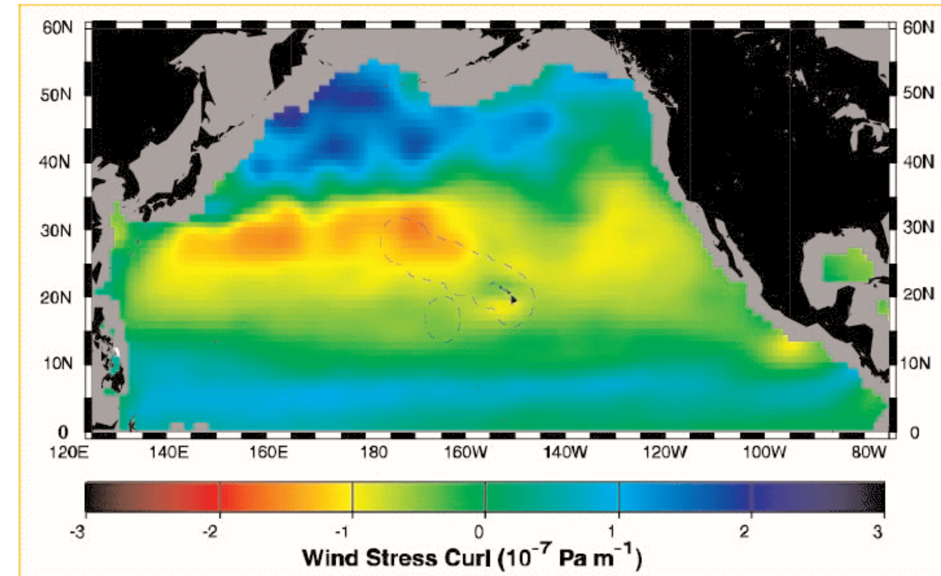


Figure 3
Climatological wind stress curl for Boreal winter (January-March). Regions of negative wind stress curl (red colors) indicate ocean convergence.

Using an array of satellite environmental sensors, oceanographers are now able to observe properties of the ocean surface with much improved spatial and temporal resolution. These properties include surface winds (QuikSCAT and other scatterometers), sea surface temperature (AVHRR and GOES), sea surface height and computed geostrophic currents (TOPEX/Poseidon), and ocean color or chlorophyll (SeaWiFS and earlier CZCS). With these modern tools, scientists are now better prepared to assess the extent of the threat posed by marine debris over the vastness of the global ocean.

Using high-resolution scatterometer winds to compute wind stress curl over the Pacific Ocean, we (Brainard et al., 2000) have confirmed and expanded upon Kubota's (1994) finding of a marine debris accumulation region centered north of the Hawaiian Islands (figure 3). Regions of oceanic convergence are most likely to accumulate marine debris while regions of oceanic divergence are least likely to accumulate marine debris. We have found regions of oceanic convergence to be highly nonstationary with pronounced seasonal and interannual variability. Convergence in the North Pacific is highest along the subtropical front in the western half of the basin during the winter months. In the vicinity of the

Hawaiian Archipelago, accumulation would be expected to be highest to the northwest and lowest to the southeast. During the summer, convergence is generally much weaker and more diffuse across the North Pacific with the region of highest convergence shifted to the eastern portion of the ocean basin several hundred miles off the California and Oregon coasts. The region of high convergence, or likely accumulation of marine debris, is strengthened and enlarged during periods identified as El Niño warming events in the tropical Pacific. During the 1992 and 1998 El Niño events, the region of convergence was observed to expand much further south to include the main Hawaiian Islands. This result partially explains the documented increase of marine debris found on beaches and reefs of the main Hawaiian Islands during 1998 (Brainard et al., 2000).

Presently, oceanographic knowledge and satellite observations of ocean conditions are being used to assist marine debris removal efforts by helping to locate areas in the Northwestern Hawaiian Islands and elsewhere that are most likely to have the highest concentrations of marine debris. From an oceanographic viewpoint, the coral reef ecosystems at Kure, Midway, Pearl, and Hermes Atolls are expected to have the highest average encounter rate of marine debris since these areas are more centrally located in the strongest mean convergence zone. Of course, bathymetry, reef structure, and local processes such as small-scale flow regimes and wave forcing also play a significant role in entangling debris on coral reefs and beaches.

These oceanographic analyses suggest that much lower accumulation rates of derelict fishing gear and other marine debris would be expected at most of the other tropical islands and atolls of the Pacific. Exceptions include the Japanese islands of the Ogasawara Archipelago, Kazan Group, and Minami-Tori, where moderately high accumulation rates might be expected. The same analysis predicted very low accumulation of marine debris in the U.S. Line and Phoenix Islands of the central equatorial Pacific; this was verified during a coral reef assessment cruise to these islands in March 2000 (Brainard et al., 2000b). A similar analysis is currently underway for the entire Pacific basin. Preliminary results indicate that wind-driven ocean convergence is less intense in the South Pacific Ocean. However, there appear to be broad regions of moderate ocean convergence, which may play a significant role in the transport and accumulation of marine debris. The utility of oceanographic analyses in other oceans to direct marine debris removal efforts should be investigated.

Michael Parke of NMFS Honolulu Laboratory is presently beginning a study to evaluate the effectiveness of using IKONOS satellite images to identify and quantify derelict fishing gear in the Northwestern Hawaiian Islands.

The IKONOS imagery is available with 1 m panchromatic and 4 m multi-spectral resolution. If he is successful in identifying individual pieces of derelict fishing gear, which are often much larger than the 1 m panchromatic image resolution, this new technology could greatly improve the efficiency of efforts to locate and remove marine debris from the coral reefs and beaches of the Northwestern Hawaiian Islands and elsewhere.

At-sea Removal

The removal of derelict fishing gear at sea, before it encounters reefs or damages wildlife, may be the most advantageous mitigation action once debris enters the marine environment. An ambitious proposal by the NMFS Honolulu Laboratory aims to investigate the feasibility of such efforts. Once the majority of the derelict fishing gear is removed from the coral reefs and beaches of the NWHI, Honolulu Laboratory scientists are proposing a comprehensive multi-agency program to begin removing derelict fishing gear at sea. By so doing, they hope to prevent much of the ecological damage that is now threatening the coral reef ecosystems and protected species of the region. This plan takes advantage of the fact that ocean currents and convergence processes do an efficient job of accumulating marine debris from around the Pacific Ocean into relatively well-defined zones. Combining satellite observations of winds, sea surface temperatures (SST), ocean color, and sea surface height, they believe they can identify general regions to direct aircraft and ships to interdict debris at sea. These regions of highest convergence would be along frontal zones of the order 100 km by 1000 km. These scales are well covered by satellite-based measurements. However, the oceanographic tools (e.g., SST, ocean color, and wind) are useful only for inferring likely positions; they do not have sufficient resolution to image the actual debris. The study by Michael Parke to investigate use of IKONOS imagery, if successful, could be expanded to evaluate whether this imagery could be used to identify individual large pieces of debris at sea. We also propose to evaluate the use of aircraft equipped with synthetic aperture radar (SAR) and/or hyper-spectral visible light sensors. These instruments should allow us to resolve scales less than 1 m, allowing individual pieces of derelict fishing gear on the ocean surface to be mapped. This information would then be transmitted to surface debris removal vessels. If provided with maps of areas of highest concentration, the vessels could then use helicopters to guide them to individual derelict fishing gear items for at-sea removal. Although this multi-level scenario presently may seem costly, at-sea removal would potentially be no more expensive per ton of debris removed than the existing methodologies and would have the significant advantage of removing the debris before it damages the coral reef ecosystems.

SUMMARY

In summary, derelict fishing gear in the Pacific Ocean originates from many types of fisheries throughout the Pacific basin. Based on surveys of derelict fishing gear in the Northwestern Hawaiian Islands, trawl fisheries and gillnet fisheries, particularly driftnets, appear to be the most dominant forms of derelict fishing gear found. This is not surprising since these two fisheries would be expected to have the highest rates of accidental gear loss. Preliminary evidence suggests that in addition to accidental gear loss, some derelict fishing gear appear to be purposefully discarded. Estimates of the magnitude of derelict fishing gear are based on beach surveys, ship-sighting surveys, trawl surveys, diving surveys, oceanographic observations, and satellite remote sensing. These surveys reveal that the ocean currents tend to accumulate marine debris in oceanic convergence zones. Using the combined information from surveys, oceanographic knowledge, and satellite and aerial remote sensing, future efforts to protect fragile coastal marine ecosystems by recovering marine debris from reefs and shoals, as well as at sea, will be greatly improved.

- Transcribed from a speech given on August 7, 2000

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ECOLOGICAL EFFECTS OF MARINE DEBRIS: THE EXAMPLE OF NORTHERN FUR SEALS

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ABSTRACT

It is impossible to make a complete list of the environmental impacts of the current human population, a population that is a thousand-fold larger than the mean population of other similar-sized mammals. One set of influences has involved our use of the seas for food and the resulting changes in marine environments. Humans harvest fish at rates that are ten to one thousand-fold larger than the mean rates of consumption by other mammalian predators. Among the many consequences are the effects of the gear used. To accomplish harvests of such magnitudes we have developed new technologies, including the development and use of plastics to make nets. In spite of the durability of plastics, fragments of fishing gear are lost, torn away, or discarded. These fragments join debris generated elsewhere, including the effluents from rivers and streams that carry garbage lost or discarded in terrestrial settings, all of anthropogenic origin and destined to impact the marine environment.

Numerous studies have been published, and several symposia have been held, to characterize and measure the effects of marine debris. Plastics often accumulate in the digestive systems and cause the death of birds, turtles, and various filter feeding species. Many fish, birds, and mammals become entangled and die. This paper uses the effects of marine debris on northern fur seals (Callorhinus ursinus) that breed on the Pribilof Islands in Alaska as an example of the general problem of marine debris. Entanglement in marine debris by northern fur seals results in reduced growth rates, altered feeding behavior, injury, impaired maternal care, and mortality. The population level consequences of such factors were manifested in a decline that occurred in the late-1970s and early-1980s.

Much has been done to tackle the larger problem of marine debris. But if we were to consider all of the cases for marine species like that of the northern fur seal, studied or not, we would be left with an important question: Can we address the issues behind and beyond the problem of debris? They involve changes in the quality and quantity of food supplies, other aspects of fur seal population dynamics, and effects on other species. More research is needed and any conclusion regarding the effects of marine debris on any one species is not basis for neglecting research or management regarding other problems. Supporting the current human population results not only in the problem of marine debris, but in many other problems in both marine and terrestrial environments.

INTRODUCTION

Industrial fishing helps provide food for a human population that is well above the normal range of natural variation for population size among species of similar body size (Fowler and Perez, 1999). Having occupied more of the earth's surface than any other mammalian species, we rely on the fishing industry to supply significant portions of our food from the marine environment. Marine fishery harvests are being taken at rates that are one to three orders of magnitude more than the average consumption rates among other mammalian consumers of the same resources, mostly through commercial fishing (Fowler, 1999; Fowler and Perez, 1999; Fowler et al., 1999). Such harvests have numerous secondary or indirect effects, some of which show in the initial documentation of their effects on ecosystems (e.g., Pauly et al., 1998; Hall, 1999; Kaiser and de Groot, 1999). We have very little understanding of the consequences of such changes to the future of the various species involved, including ourselves. It is important to recognize that there are repercussions to what we are doing, especially those that may result in risks for future generations. These include the effects of the technologies that make such harvests possible.

One technology that has made it possible to harvest fish at current rates was the development of plastics, particularly those used in nets that were introduced in the 1940s and 1950s and became prevalent by the 1960s. Numerous review articles and books serve as sources of information about the effects of plastics in various environments, including their influence on various elements of the marine environment (e.g., Shomura and Yoshida, 1985; Alverson and June, 1988; Shomura and Godfrey, 1990; Coe and Rogers, 1997). Ghost fishing (Breen, 1990; Hall, 1999) has direct effects on species of economic interest as well as both their prey resources and predators. Entanglement and ingestion of plastic debris have been documented as factors contributing to the mortality of numerous species, including many marine turtles, sea birds, and marine mammals (e.g., Laist, 1997). Plastics from worn or discarded fishing nets are one of the main sources of debris involved in the entanglement of marine mammals.

Between the mid-1970s and the early-1980s the population of northern fur seals on the Pribilof Islands experienced a decline from which it has not recovered. This decline occurred a few years after a peak was observed in the portion of juvenile males seen entangled in the commercial harvest. Concern generated when the problem was first recognized and gave rise to a number of studies to examine the effects of marine debris on individual fur seals and attempts to measure the effect on their population.

The entanglement of northern fur seals is one of many examples of the kinds of environmental effects of a human population so abnormally large in comparison to other species. This particular effect is the result of the use of plastics in fishing, shipping, and other activities in support of this population and is one example of the many effects of commercial fishing in that regard.

EFFECTS OF MARINE DEBRIS ON NORTHERN FUR SEALS

Northern fur seals (as well as other pinnipeds around the world, Fowler, 1988; Laist, 1997) become entangled in marine debris of various types, nearly all of which ends up encircling their necks (with some around their heads or shoulders and upper bodies). Most is netting of various kinds (predominantly trawl net fragments, but also seine and gill net material), plastic packing bands, and twine or ropes of various kinds (see Fowler et al., 1994 and Stepetin et al. 2000 for an accounting of the kinds of items found on northern fur seals, and further references regarding this issue). Presumably, most of the entanglement occurs as a result of curious play with such materials (Bengtson et al., 1988) and is therefore a problem of greater consequence to younger seals than it is for the adults.

The history and details of the study of entanglement of northern fur seals, as summarized below, is documented in a variety of reports and documents, some of which are referred to in overview papers of Fowler (1987), Fowler et al. (1990) and Laist (1997). The monitoring of marine debris on northern fur seals continues (Stepetin et al., 2000), thus offering the opportunity for continued analysis in the future.

BEHAVIORAL EFFECTS

Being entangled in debris reduces the ability of fur seals to swim. Their activities are altered so that more time is required for finding food and for resting, resulting in less time for other activities such as returning to breeding colonies to nurse pups. In the process, feeding cycles and diving behavior are affected.

For example, Feldkamp et al. (1989) found that captive northern fur seals exhibited a marked reduction (75% for the circumstances of their study) in the time fur seals spend swimming when they are entangled (as compared to normal conditions with no debris to impede their movement through the water). Entangled animals spent more time resting (138% more in the Feldkamp study) than they did without debris.

Yoshida et al. (1990a) also conducted studies on captive northern fur seals in a marine aquarium and found that entanglement inhibited activity in general. In this study, debris of 1 kg and 2 kg masses were placed on two adult female fur seals and radio transmitters were attached with nylon harnesses, including one on a control seal. The behavior of all three seals was monitored with receivers that recorded their activity. Average total daily active periods were 9.6 h/day for the control, 4.1 h/day for the seal entangled in 1 kg of netting and 1.4 h/day for the seal in 2 kg of netting. Activity was similar among all three seals after removal of the debris.

Another behavioral factor affected by entanglement is the cyclic foraging patterns among both male and female northern fur seals. During the breeding season, females leave their breeding colonies to feed and then return to nurse their pups.

These are cycles that are repeated for a number of weeks after the pups are born (Gentry, 1998). A study of the effects of entanglement on females was conducted in 1985 (DeLong et al., 1988). Forty females were fitted with radio transmitters, all from the Zapadni Reef breeding colony on St. Paul Island in the Bering Sea. Twenty were entangled in 200 g pieces of trawl webbing of 23 cm mesh and the other twenty served as controls. These seals were then monitored continuously with a programmable receiver and chart recorder to determine whether they were present or absent from the breeding colony. Furthermore, visual scans were conducted daily between July 22 and October 13. The mean duration of the trips to sea for the entangled and control seals in this study is illustrated in figure 1. As can be seen, the feeding trips for entangled seals were roughly twice the length of those for the controls.

Similar work with juvenile males showed that they also exhibit altered feeding cycles (Bengtson et al., 1989). Cycle length was increased by being entangled, consistent with the results of studies on females, and more time was spent on land, an option probably not so available to females whose pups depend on them for food.

The diving behavior of entangled northern fur seals is also affected. For example, entangled seals do not dive as deep as they would otherwise. Bengtson et al. (1989) used data from time depth recorders attached to seals to compare the diving behavior of three entangled seals with that of three control seals, all juvenile males captured and tagged in 1986 on St. Paul Island. The debris on the entangled seals was, in all cases, less than 1 kg in weight. The results indicated that the entangled seals made about the same number of dives as did the control seals, but the entangled seals did not dive as deep as the controls did. When diving to any particular depth, the entangled seals spent more time during their dives than did the control seals. Thus, the depth and duration of dives was altered by being entangled, but no change in the frequency of dives was detected in this study. Entangled seals made longer and more shallow dives than seals without the effects of debris.

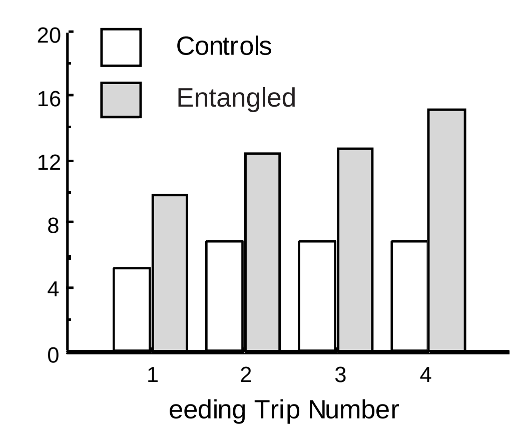

Figure 1
A comparison of the mean length of feeding trips for entangled female northern fur seals fitted with radio transm itters and for seals fitted only with radio transmitters, for the first four feeding trips in the study (from DeLong et al., 1988).

ENERGETIC DEMANDS

The energetic drain on seals caused by the drag of entangling debris is greater than the drag a seal experiences while swimming normally. Studies by Feldkamp et al. (1989) showed that fur seals of 4 to 17-months of age spent twice as much energy swimming at 1.1 m/s with 200 g of entangling trawl net compared to seals without debris. This is consistent with work on California sea lions (Zalophus californianus) in which it was shown that individuals entangled in 400 g pieces of net experienced a four-fold increase in energetic demands. As would be expected, both studies showed that energetic demands increase with swimming speed and the size of the entangling debris.

These conclusions are supported by the work of Yoshida et al. (1990b) who observed a decrease in swimming speed in relation to an increase in the size of entangling debris in their study with captive animals. Net fragments of six different sizes (0.5 to 3.0 kg) were placed on the necks of eight fur seals (two males, six females) in an aquarium and their swimming speed was recorded using visual observations of each individual while swimming over measured distances. Another measure employed in this study was that of the time required to capture fish. Consistent with the studies reported above, the time required increased in a relationship that was nearly a linear function of net size. The mean time to catch live fish for control seals was about 15 seconds whereas seals entangled in 3 kg of netting required an average of about 157 seconds. Thus, being entangled contributes to a decrease in foraging efficiency. Entangled seals spend more energy swimming, consume less in the time during which they forage, and have less energy available for swimming.

WOUND DEVELOPMENT

Of all the seals that get entangled, a few are entangled in debris that is sufficiently small enough for them to capture food, grow, and survive to be seen in studies to monitor entanglement. However, the resulting growth in body size of these seals produces pressure against entangling debris. The wear of movement, in combination with this pressure, results in growing wounds and infections. Fowler and Baba (1991) summarized the data on wound size for entangled male seals sighted in research on seals observed after 1983. Some of these seals were involved in studies in which the debris was purposely left on the animals (to estimate mortality caused by entanglement). Twelve entangled seals were initially sighted without observable wounds and then were resighted again in the following year. After one year of being entangled, three of these seals had no wounds, one showed the initial phases of wound development, and the remaining eight had full 360° wounds around their necks. Another eight had wounds that were less than 360° when first encountered and were then sighted on one or more occasions in subsequent years. All but one of these had developed full 360° wounds by the first (n = 5) or second (n = 2) year following the initial observation.

GROWTH RETARDATION

Based on the results of studies on energetics, it is no surprise that entangled fur seals either lost weight or there was a reduction in their growth rates; some of which may be attributable to the effects of wounds and infections caused by entangling debris.

Table 1 shows the weights of juvenile male seals taken in the commercial harvest of 1982 (Scordino and Fisher, 1983). The mean weights of all entangled seals with wounds were less than those for the controls (not entangled). In two cases, entangled seals with no wounds (ages two and three) showed mean weights less than the controls and in all cases the entangled seals with wounds showed mean weights less than entangled seals with no wounds. If there were no difference in growth, the probability of this combination of observed differences (or more extreme) occurring is less than 0.10. As reported in Scordino and Fisher (1983), there were cases in which entangled males were observed with very obvious stunted growth.

Table 1. Body mass (kg) of juvenile male fur seals of four different age categories taken during the commercial harvest of 1982, St. Paul Island, Alaska (from Scordino and Fisher, 1983).

	Age (years)			
Entanglement category	2	3	4	5
Controls	21.4	28.5	35.3	50.9
Entangled (no open wounds)	21.3	27.8	36.0	52.8
Entangled (with open wounds)	14.7	26.6	32.2	44.5

DeLong et al. (1988) also found indirect effects on the growth of pups whose mothers were entangled. In addition to monitoring the 40 adult females (20 entangled females and 20 control females), the pups from each of the two groups were also marked and weighed. The first weights for these pups were obtained in July at their first capture. Pups from each group were subsequently recaptured and weighed again in August and a third time in September. Pups nursed by control females gained a mean of 2.1 kg (n = 19) between the first and second weighing and 3.6 kg (n = 14) between the second and third. By comparison, the surviving pups of the entangled females gained an average of 1.2 kg (n = 12) and 2.2 kg (n = 7) for the same periods (figure 2).

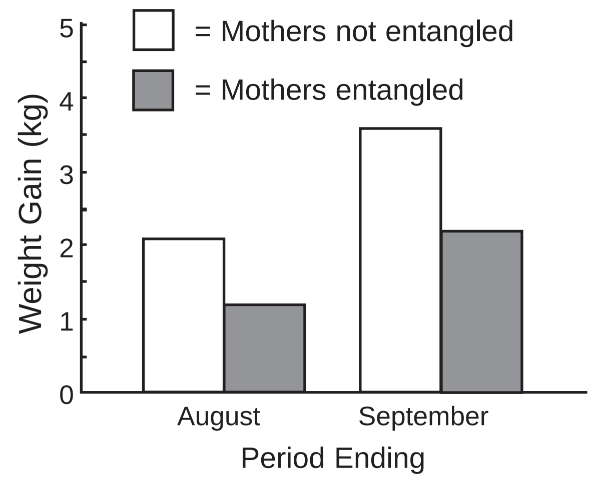

Figure 2
Comparison of the gain in mass observed from July to August, and from August to September, for two groups of fur seal pups: 1) those whose mothers were entangled (n = 12, 7), and 2) those whose mothers were free of entangling debris (n = 19, 14), (from DeLong et al., 1988).

MORTALITY

Individual northern fur seals die as a result of the effects of entanglement, as would be expected on the basis of the impacts reviewed above. Starvation, exhaustion, infection, greater vulnerability to predators, and diseases are all involved to one extent or another. Knowing this emphasizes the importance of assessing the extent of mortality rates, especially in view of its potential importance at the population level. Various studies have examined this issue for northern fur seals.

In the study by Delong et al. (1988), entangled females and their pups were monitored over the course of the 1985 season to determine the indirect effects of entanglement. DeLong et al. (1988) indicated that 3 out of 17 entangled adult female seals failed to return from their first trip to sea. Four failed to return after their second trip, and two more did not return after their third trip. Thus, over half (9 of the 17) failed to return within the first three trips to sea, a period of time less than about two months. By contrast, only one of the 20 control seals did not return, her failure occurring on the fourth trip to sea. Such observations can be explained either by behavioral changes or mortality. In either case the pups suffered higher mortality.

DeLong et al. (1988) conducted surveys and monitoring again in 1986 to test the hypothesis that adult female seals from the entangled group from the 1985 study would be resighted in the same proportion as seals from the control group. During weekly surveys conducted in July, August, and September of 1986, 12 females from the control group, and two females from the entangled group were resighted. Both of the females from the entangled group were animals that had lost their entangling debris during 1985; none of the 17 that retained their debris in 1985 were resighted in 1986.

DeLong et al. (1988) concluded that the females that did not return in 1985 either abandoned their pups or died at sea. Mortality probably prevented the observation of those not sighted again in 1986.

DeLong et al. (1988) also report significant indirect effects on survival of pups (before weaning and during the time that they depend on their mother's milk) that are attributable to the entanglement of their mothers. Of the pups born to the 17 females that retained their entangling webbing, only 6 were alive at the end of the study the first season, while 19 of the 20 pups from the control females survived. Thus, even when an entangled adult female is capable of returning to nurse her pup, the pup's chances of surviving are reduced.

Other studies of entanglement and its effects on the northern fur seal population involved juvenile male northern fur seals. Between 1985 and 1992, 153,850 juvenile male seals were sampled in surveys (referred to as roundups that involved sampling with replacement, Bengtson et al., 1988; Fowler and Ragen, 1990; Fowler et al., 1990; Fowler and Baba, 1991). Entangling debris was left on the sampled seals (n = 265) when they were encountered during the first three years of this study, and each entangled seal was tagged along with two control seals of similar body size. After the first three years, debris was removed from entangled seals when they were encountered. In years subsequent to the initial marking, the ratio of the proportion resighted for each group was used to calculate an estimated survival of both entangled and disentangled seals (Fowler et al., 1990). This survival was expressed as a fraction of normal survival (i.e., survival of the control seals). Figure 3 shows the declines in the portion of each group of seals resighted by year of recapture subsequent to their release.

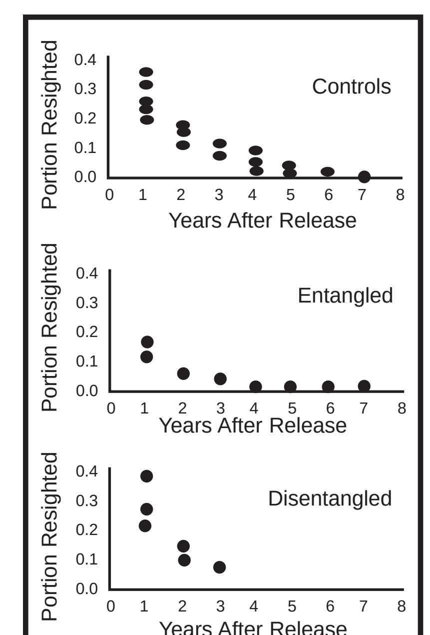

Figure 3
The fraction of seals resighted subsequent to release in samples from St. Paul Island, Alaska, from 1986 through 1992, that were never entangled (top panel), entangled (middle panel), or had entangling debris removed (lower panel), (updated from Fowler et al., 1999).

The relative rates of recapture clearly indicated a marked effect of entanglement on survival. Analysis of the data presented graphically in figure 3 resulted in an estimated survival for entangled seals that is about one-half that of the survival they would normally experience (an instantaneous mortality rate caused by entanglement of about 0.69, Fowler et al., 1990; Fowler et al., 1994). Disentangled seals experienced a survival about 93% of that for controls (Fowler et al., 1994), thus indicating that removal of debris has a marked effect in preventing mortality, but some residual effects of entanglement seem to remain, nevertheless.

POPULATION EFFECTS

Studies such as those above contributed to information to help measure the effects of entanglement among northern fur seals at the population level, and emphasized the importance of doing so. It became clear that the animals surviving to be observed in small debris represented only a small fraction of those that became entangled. Most had died and were never seen because almost all seals in larger fragments of net appeared to have either died or left the reproductive population after less than one year in the experimental studies reviewed above.

The timing of the decline between the mid-1970s and the early-1980s corresponded to a period during which the population effects of earlier entanglement would have been expected had there been population models such as were produced later (Swartzman, 1984; Fowler, 1982; Reed et al., 1987; French et al., 1989; Reed et al., 1989; French and Reed, 1990). This timing led to the concern that prompted the studies reviewed above and placed emphasis on examining population level effects in a variety of ways.

Several alternative approaches were employed to examine the degree to which mortality caused by entanglement has been influential in the dynamics of the northern fur seal population, especially that of the Pribilof population. These included: (1) various modeling studies; (2) several analyses of data on observed entanglement rates in correlation with population change; and (3) estimates of mortality rates caused by entanglement after accounting for various factors such as the unobserved entanglement and mortality involving large debris.

Modeling began with the work of Fowler (1982) where it was concluded that the effects of entanglement should be considered as a factor in the decline in fur seal numbers observed in the late-1970s. Swartzman (1984) and Swartzman et al. (1990) then developed models that showed the plausibility of mortality from entanglement as a primary cause of this decline. These models were more sophisticated than that of Fowler (1982) by including age structure (Fowler, 1987). Other modeling work (Reed et al., 1987; French et al., 1989; Reed et al., 1989; French and Reed, 1990) resulted in similar conclusions.

They showed that entanglement-caused mortality could clearly account for population trends observed between the early-1970s and mid-1980s. This work also demonstrated the possibility that a decline in observed entanglement rates (even a 20% reduction) might result in a stabilizing of the Pribilof Islands population (the population has been relatively stable since the early-1980s following the peak in observed entanglement rates in the early- to mid-1970s). Thus, among the many alternative factors known to contribute to mortality, entanglement has been the only factor for which there was a demonstrable change with a magnitude and timing that corresponded with the decline. These modeling efforts clearly established the plausibility of entanglement as the primary factor contributing to the decline between the mid-1970s and early-1980s, keeping in mind that the effects of other factors continued to play their roles.

Other studies also support the conclusion that entanglement caused mortality was a primary factor in the decline of fur seals on the Pribilof Islands in the late-1970s and early-1980s. Some of these studies used information on correction factors to account for the variety of factors that prevent most mortality from being directly observed. These factors included age, to account for the fact that small entangled seals would not be seen (they could not return to the breeding islands if they were entangled and do not return under normal circumstances in any case). The most significant factor is the size of debris; as demonstrated in other work, seals entangled in large fragments of trawl netting cannot return to the islands to be observed during entanglement surveys. Further considerations involved the effects of sex, natural (nonentanglement related) mortality, and other characteristics of entangling debris (e.g., mesh size and type). Such factors were combined to estimate the mortality rate caused by debris within the fur seal population as a whole. These efforts resulted in an estimated entanglement-related survival of about 0.85 (an instantaneous mortality rate of about 0.16) among younger age groups. Thus, these studies indicate that there was an extra mortality rate of about 15% per year that was attributable to the effects of entanglement (Fowler et al., 1990). This estimate applied to conditions of an observed entanglement rate of about 0.4% among the juvenile males. The corresponding extra mortality of the higher entanglement rates observed in the early- to mid-1970s would be more than enough to explain the decline in population in the late-1970s. Such results added to the difficulty of ruling out the conclusion that entanglement was a primary factor.

Similar results emerged in studies of the correlation between the rate of change in the fur seal population and observed entanglement rates (Fowler, 1985; Fowler, 1987). The independent variable in most such studies was the entanglement rates observed a few years earlier when mortality would remove (or prevent the reproduction of) females that would normally have been recruited to the reproductive population. Figure 4 shows one such relationship, extended from earlier work to take advantage of more recent data and cover the period from 1967 to 1991 (for entanglement rates) and 1971 to 1996 (for rates of change). Data after 1994 can not be used yet because rates of change beyond 2000 are not available. As predicted by earlier modeling work, the reduction in entanglement rates observed recently has corresponded with a relatively stable population (little change has been observed in the numbers of pups born in the Pribilof population of fur seals since the early-1980s). The entanglement rates observed in recent years have remained at about 0.2% (Robson et al., 1997; Stepetin et al., 2000), and such observation can be used in future correlative analysis when the corresponding rates of change are available.

The results of this component of studies on population effects of entanglement (as shown in figure 4) indicate that entanglement results in the equivalent of a mortality rate of about 15% spread over the entire population. This is seen in the difference between the rate of change at an entanglement rate of zero (8% per year increase) and that at the highest rates of observed entanglement (about a 7% or 8% per year decline).

Another correlative study looked at the mortality unexplained by the relationship between pup survival and juvenile survival (the first 20 months of life at sea, Fowler, 1985, 1987) between 1950 and 1965. This relationship appeared to break down in the late-1960s through the mid-1970s at a time when entanglement rates were observed to increase. Multiple correlation analysis resulted in an estimated additional mortality of 15% at an entanglement rate of 0.4%, again sufficient to have been the primary cause of the decline between the mid-1970s and early-1980s at the higher entanglement rates observed in the early-1970s. Other correlative studies are presented in Fowler (1985).

The consistency of results in the modeling work, the estimated mortality rates, and the correlation analyses led Fowler (1985, 1987) to conclude that the decline in fur seal numbers observed in the late-1970s, and the failure to recover in the early 1980s, can be attributed to the effects of entanglement. Much as the decline between the 1950s and late-1960s can largely be attributed to the effects of the harvest of females (York and Hartley, 1981). A similar conclusion was reached by Fowler et al. (1990). This conclusion comprises the basis for management action as mortality rates of 15% for fur seals cannot be within the normal range of natural variation of mortality caused by other species (e.g., Fowler et al., 1999). It should be obvious that the significant effects of entanglement are confined primarily to the period when observed entanglement rates are highest (i.e., the period between the early-1970s and early-1980s), although we cannot rule out lingering effects, nor that the low levels of entanglement observed currently are not having unmeasured effects.

ECOLOGICAL EFFECTS OF MARINE DEBRIS:
THE EXAMPLE OF NORTHERN FUR SEALS

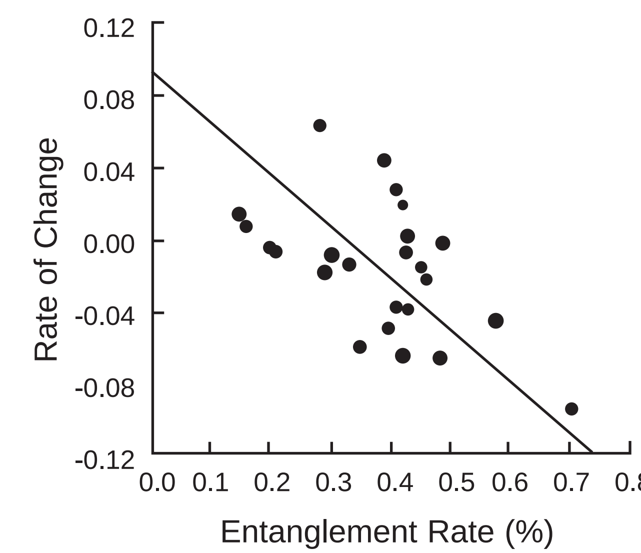

Figure 4
The correlation between the rate of change in numbers of pups born from 1972 to 1996 (based on a running mean of 3) and the entanglement rate observed among subadult male northern fur seals from 1967 to 1991 (i.e., with a lag of 5 years, based on data available at the National Marine Mammal Laboratory, Seattle, WA; see Fowler, 1987).

DISCUSSION

Commercial fishing is a complex process with many effects on the various species within marine ecosystems. There is little doubt that marine debris is one of these factors. The effects identified for fur seals and their population on the Pribilof Islands are not alone.

Although it is likely that the decline in the late-1970s may not have occurred without the effects of entanglement caused mortality, other factors can not be ignored. During the decline, other factors had their normal effects in contributing to natural mortality. Other factors may have involved other anthropogenic effects. For example, such factors could easily include a reduction in the carrying capacity (Fowler and Siniff, 1992), especially in the years following the more prominent effects of entanglement. In spite of its apparent prominence for a restricted period of time, it would be a critical mistake to ignore other effects of over fishing, contaminants, or global climate change, especially at times of low entanglement rates. Although the effects of the commercial harvest of female northern fur seals were probably greatest during the 1950s to the late-1960s (York and Hartley, 1981), lingering effects could well extend into later periods (Fowler, 1995). We cannot use information that indicates that entanglement was, and may still be, a serious problem to divert attention from such matters. Research on the effects of changes in the composition (Merrick, 1995), depletion, and redistribution of resources is imperative because their effects could easily be significant at any time. All problems that can be identified and measured need to be addressed to fulfill the tenets of adequate management (Fowler et al., 1999).

In focusing on measuring the effects of marine debris as one such problem, for at least one period of time, it is clear that the combined effects of factors such as wounds and altered behavior contribute to mortality and its resulting population-level effects for northern fur seals. From a management point of view, the burden of proof now lies not in proving that there are population-level effects, but that there are not (Mangel et al., 1996; Dayton, 1998). The same would be the case for the genetic effects of harvesting (Fowler, 1995), or a reduction in carrying capacity (Fowler and Siniff, 1992). Much is now being done to mitigate the problems of marine debris (e.g., Debenham and Younger, 1991; Coe and Rogers, 1997). In view of the information we have on northern fur seals, in combination with information on other problems created by marine debris, it is important to undertake management action, including beach cleanups, and the discarding of waste netting in ports (Debenham and Younger, 1991; Alverson and June, 1988). A wide variety of such efforts are in place, including educational programs to address the issue (National Research Council, 1995; Coe and Rogers, 1997).

The collective effects of marine debris are staggering in their magnitude if we consider all of the species that may be affected by marine debris, not to mention the problems observed in terrestrial settings. The role of plastics in the marine debris problem must be considered in the context of the good they serve (in many areas, e.g., packaging, medicine, fishing, entertainment, apparel, protective gear, and instrumentation). Ultimately, the following questions must be asked: Is the good outweighed by the long-term consequences of the global problems and in the marine environment in particular? What if these problems are only the small tip of a very large iceberg in parallel with the few surviving entangled fur seals left to be observed after the mortality experienced by so many others? Behind the magnitude of the problems observed is one very important factor: the magnitude of the human population. Plastics and other debris are, in part, the result of technology that has allowed (even promoted) the growth of the human population to its current size. Can the current human population be sustained in view of its many consequences? Only one of these effects is apparent in the small example provided by the effects of marine debris. And only one example of this larger problem is seen in the effects of a few kinds of debris on northern fur seals.

We have been fortunate with northern fur seals because their life history characteristics and breeding behavior have made it a convenient species for studying the effects of marine debris. In spite of the limitations of data on northern fur seals, our success in studying this species has been made possible by their annual return to the breeding islands where they are seen in large numbers. In these locations they have been available for field studies, particularly studies of the effects of marine debris. If we had the opportunity to study in equivalent detail the physiology, behavior, and population dynamics of all species similarly affected, it is clear that the extent and nature of the effects of marine debris would be better appreciated. Affected species would include: filter feeders that filter microscopic plastic particles from marine waters; birds that use plastics to construct their nests and feed their young; and other species that are effected by ghost fishing, entanglement, and ingestion (Coe and Rogers, 1997; Shomura and Yoshida, 1985; Shomura and Godfrey, 1990). Such studies would need to be expanded to include the effects of chemicals released during the breakdown of plastics, and chemicals concentrated by plastics that have surfaces to which the molecules of such substances are attracted.

Based on what we have learned from the northern fur seal example, will we know how to solve the underlying problems even if we understood all that there is to understand about debris, and all of the species it affects? Short-term superficial attempts to solve the problem of debris have their own unintended consequences. For example the initial manufacture of plastics requires energy that results in carbon dioxide to contribute to problems such as global warming, and mitigation through recycling plastics only adds to such problems. Other alternatives pose other problems. Landfills to dispose of plastics require both energy and space, both of which we are using at abnormal rates compared to other species (Fowler and Perez, 1999). Incineration results in unwanted by-products. Every way we turn, there are consequences to our actions. These are seen, in their most painfully obvious way, if we contemplate giving up the use of plastics entirely. But the question remains: Is our use of plastics for their short-term benefits overshadowed by much larger long-term consequences that future generations will experience?

ACKNOWLEDGMENTS

I would like to thank the many colleagues with whom I have worked over the past two decades for their efforts in the research on entanglement and its effects on northern fur seals. A complete list of people is beyond the scope of this paper, but most are found as authors of the papers in the literature cited below. Society owes them a debt of gratitude for their help in understanding the magnitude of the problem of marine debris. I greatly appreciate their work and dedication. I would particularly like to thank Jim Coe, Gary Duker, Jean Fowler, James Lee, Rolf Ream, Bruce Robson, and Jeremy Sterling for insightful and helpful comments in their reviews of previous drafts.

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ECONOMICS OF LOST FISHING GEAR

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INTRODUCTION

"The homilies of economists never change."[2]

Six years ago at the Third International Conference on Marine Debris, the papers on economics made four important points: (1) debris on beaches decreases the prosperity of a community as well as the ecosystem (Smith, 1997); (2) moral suasion only goes so far (Sutinen, 1997); (3) a waste management model may be a good way to identify points of intervention for reducing the social costs of marine debris (Laska, 1997); and (4) a cost-benefit perspective has much to offer in attacking the issue of marine debris (Kirkley, 1997).

Aside from debris on the beaches, it did not seem-based on the conference report-that much quantitative information was available on the economic cost of marine debris, and that would seem to be the same today.[3] Hopefully we will learn to the contrary during this conference.[4]

Why does it seem that little has been learned about the costs of marine debris? I think it is because of the wide-open and elusive nature of the ocean, the long time horizons between loss and impacts, and the socialization of private costs into the commons that are our oceans. And because, if there is no change in institutional and regulatory structure concerning lost fishing gear, there is no behavioral change for economics to evaluate. I will identify some areas for further economic analysis later in this paper. A simple comprehensive accounting of the costs of marine debris would be useful, but this is an applications problem waiting for a public policy initiative.

In this morning's talk, I would like to summarize an economic perspective on lost fishing gear, but I cannot claim to be any type of expert. My "expertise," if you want to call it that, will be in applying economic and political theory, spiced with a little time using commercial fishing methods aboard a NOAA research vessel, and some familiarity with what are important economic and operational issues to fishing boat owners and captains. What I have to say won't be very brilliant. Hopefully, it will be helpful just to remember some first principles.

PRIVATE VS. SOCIAL COSTS AND BENEFITS

To begin, let us consider the direct cost of replacement of lost fishing gear to the vessel owner (a cost frequently shared by the crew). Lost fishing gear represents a negative externality in the production of seafood, and this negative externality is generalized to the rest of society. Avoiding the loss of fishing gear represents a specific cost to fishing vessels in terms of capital and operating expenses, allocation of labor time, the risk of retrieval, and opportunity cost of lost fishing time (during replacement or retrieval). The fishing vessel owner and captain have to balance these costs with the benefits of avoiding this gear loss.[5] The social (economic) costs of lost fishing gear is much more dispersed, both in time and place, although when the cost is borne, it is frequently borne very directly.[6] More dispersed costs to the marine ecosystem and its users (e.g., beach-goers, endangered species, fouled props, pristine environments, ghost fishing) are frequently of a low cost per incident, but these incidental costs frequently accumulate to substantial losses. Indeed, at the previous marine debris conference, considerable effort was directed toward social costs of beach debris borne by the public as beach-goers (and it is in this area that most economic effort appears to have been directed). The economic valuation of endangered species, as was undertaken as a result of the Exxon Valdez accident, is another type of research that should contribute to knowledge of the social cost of marine debris (including lost fishing gear), as long as the physical and biological processes of the interaction between this debris and various endangered species are well understood.

POINTS OF INTERVENTION

The economic (and public policy) problem is how to equilibrate net benefits across various points of intervention in attacking this problem, and when to accept that doing further may not be worth the cost since it would be more efficacious to apply regulatory energy toward other issues. Since fishing is a process, it is critical to understand the mechanics, economics, and sociology of its activities and their interactions. On this, it would appear more research is warranted (i.e., at the upstream side of the equation) and this conference's industry panel may offer good information in this regard. One way to approach this would be to identify those physical and operational points in the fishing process where intervention is optimized. To do so requires more than the type of listing presented here.[7] As in any risk management model, it requires prioritizing the threats, evaluating the benefits and costs of intervention, and acting upon those evaluations.

These points of intervention would include (amongst others):[8]

- Choice of fishing gear (initial technology)
- Maintenance of fishing gear
- Conditions for using fishing gear
- On-board facilities for secure storage
- Fisheries regulations
- Shore-based facilities for storage and disposal
- At-sea or on-land retrieval

As Laska (1997) points out, given a particular type of human activity (a given that may be challenged in some circumstances), there are a variety of choices that govern the technology used in that activity and how that may contribute to marine debris. In terms of lost fishing gear, issues have been raised about its biodegradable properties, its needs for at-sea repairs or replacement (which may contrast with biodegradability), its long-term durability, including connections to floats, markers, etc., and a range of other gear properties that represent capital costs. The problem for the fishing vessel owner is how to balance up-front capital costs with ongoing maintenance and replacement costs.[9] Maintenance is also shared by the crew through expectations that they will keep gear up during steaming and down time, as well as through gear fabrication and breakdown following fishing trips and seasons. Clearly there are some real skill and motivation issues here and labor economic issues that economists have grappled with for many years in other fields. But in terms of both capital and maintenance costs, the fishing vessel owner is balancing the up-front costs with the costs incurred by gear loss. These include not only the direct cost of gear replacement and repair, but also of lost fishing time (and expected revenue) and occasionally of fouling one's own prop.

The next point of intervention involves the conditions in which gear is set and retrieved. One of the well-known examples of fishing gear loss is the misplaced transfer of cod ends containing the product of a trawl net from the catcher boat to a processing or transfer vessel. Obviously this represents a double cost to the fishing vessel: the need to replace expensive gear; and the lost income from the day's fishing. So there is every incentive for a fishing vessel owner and captain to minimize this risk. But such incidents remain and may represent a function of weather and seas, the tiredness of the crew and the myriad other factors featured in a complex fishing operation. In the lobster fishery, hanging up a string of traps on a bottom protuberance is a similar problem, or having one lobster boat setting its trap line across another's. For longline fishing, it may be the effect of a passing vessel cutting the line and a strong current taking the line away, or it may be a large shark or bill fish tangling the line into an inoperable ball. In each of these cases the problem for the vessel captain is how long to spend trying to retrieve this gear.

Then there is the question of how fishing gear is stored on-board. It should be clear that to the fishing vessel operator, there is every incentive to keep good gear secured since it is costly to purchase and to replace. But the same may not be true of gear in disrepair or remnants of gear. Fishing vessels tend to be rather tight quarters with useable space at a premium, and so the storage of gear remnants, like that of other on-board debris is at best a problem.

Similar concerns relate to the availability of shore-based facilities for the storing and disposal of fishing gear. While MARPOL makes a number of requirements in this regard, it was apparent to the participants of the 1994 marine debris conference that this remained a problem. A quick look at the docks in Honolulu suggests this is still a problem. Clearly there is an incentive for fishing vessels to return their gear to land and reuse the gear in future fishing seasons (if there are to be future fishing seasons and if the cost of storing that gear does not exceed the price required to replace it whenever the vessel re-enters a fishery). And the incentive to return broken or destroyed gear or gear remnants relies more on moral suasion and the (apparently) low risk of a MARPOL compliance violation than on any purely economic motive.

These operational points raise questions about the governance regimes (regulations) affecting fishing operations. In a derby fishery, where the number of boats is greater than what the resource can easily sustain, there is a tendency for vessels to operate at a high intensity. Some of these disincentives to good fishing operations will tend to exacerbate gear problems. On the other hand, where a fishery management regime fosters a community of interest amongst its participants and allows for a more reasonable level of operations, then gear problems are probably reduced. The question, it seems, is to recognize the impact on the risk of losing gear at the same time that one considers other aspects of fishery management policy such as biological over-fishing, habitat destruction, and crew safety (each mandated by the Magnuson-Steven Fishery Conservation and Management Act in the U.S.).

Finally, there is the question of at-sea or on-land retrieval of lost gear. The cost of at-sea retrieval of lost fishing gear is a difficult calculus for fishing vessel captains, as previously indicated. But there is also the possibility of fishing vessels retrieving gear and gear remnants otherwise lost at sea by other vessels. After all, it is fishing vessels that are most prevalent at sea in conditions that are not restricted to simply steaming through, and it is fishing vessels that are most adept at stopping and turning and hauling material over the side in their routine operations.

Whether lost fishing gear (at least floating gear) can be efficiently retrieved while at sea by other vessels depends largely on the degree to which the gear can be tracked and found or where it accumulates. Similarly, retrieval of gear as it meets the land may also be an efficient choice if there is an organized approach to doing so (with due respect to the sometimes heroic efforts of my fellow marine scientists, I'm not talking about NOAA, NMFS, and the Coast Guard going into the gear retrieval business). Again, it is a question of the cost of gear retrieval, the basis for financing these costs and the net benefits that would derive from such retrieval.[10]

Clearly these points of intervention do not exhaust the possible list. They are provided as an impetus to identifying both upstream and downstream opportunities, and to identify different ways to intervene in the marine debris process. There is often a tendency within government to look to the regulatory solution, by which I mean the prohibition on this or that, as if regulations were free, or at worst, costly, to the violator. Regulations have a wide range of social costs, of which enforcement is but one; thus, it is important to look at a variety of ways for improving the internal incentives for reducing the quantity and impacts of lost fishing gear.

ECONOMIC METHODS OF INTERVENTION

There is a perspective in neo-liberal economic development practice known as "getting the prices right." It basically means equilibrating private and social costs (or minimizing social costs). Without engaging in the debate over the appropriateness of this approach to the Third World, it does offer quite a bit to the marine debris issue. In particular, because so much of the cost of lost fishing gear is socialized away from the source of the debris, the private cost of fishing gear and fishery products (i.e., seafood) is lower than would be appropriate if the full social costs were borne at the point of production. Therefore it would be nice if the full social costs were privately borne. If they were, it is likely that different choices would be made in the choice of technology, conditions of gear use and efforts at retrieval. And it is here that economics focuses on incentives (and disincentives) (i.e., what are the financial factors that might yield a change in behavior so that fishing gear is lost less frequently? When it is lost, can more resources be marshaled to mitigate its effects before it is too late?).

Based on the points of intervention previously identified, there are a variety of potential methods for economic intervention in the marine debris process. These include an explicit accounting of fishing gear use, deposits on new and replacement gear, and insurance. In these, it should be possible to determine whether the amount of gear actually lost by a particular segment of the fishing industry is worth the effort required to set up an incentive and disincentive system. To do so requires the explicit accounting of both gear use and the return of spent gear to the land. There are also institutional changes that may serve to maximize the incentives for gear retrieval. Finally, it is important to realize that the cost of these interventions may not be particularly great to individual vessel owners. They are not unlike oil pollution abatement insurance that many vessels already carry. But they will only be manageable costs if the incentive structures are sufficiently generalized. There are economies of scale in creating these forms of mitigation:

- Incentives for gear choice
- Costs of shore-side disposal
- Regulatory climate concerning fishing operations[11]
- Incentives for appropriate gear disposal
- Incentives for lost gear retrieval
- Liability for gear damage
- Insurance for gear removal

For economists, incentives (disincentives) generally devolve prices and other monetary instruments, as can be seen by the previous list. This does not preclude other forms of intervention, but it does stress that non-monetary measures generally have a range of hidden costs that reduce their effectiveness. Calculating the transactions and adjustment costs of non-monetary measures is important to insure that the costs and benefits are appropriately distributed amongst the interested parties, including fishing vessel owners and the general public.

SOCIO-POLITICAL OPPORTUNITIES

The problem of lost fishing gear also raises a number of issues concerning the institutional structure in which fishing occurs. The following provides a brief listing of the types of issues that need consideration:

- Recognizing the nature of the economic system
- Private incentives
- Regulatory regimes affecting fishing operations
- Communities of interest or disinterest
- Involving the fishing community
- Education and moral suasion
- Appropriate levels of enforcement
- Public/private partnerships
- International agreements

These represent opportunities for tackling this problem from a variety of perspectives. Each effort to do so will provide new information for subsequent adaptation of the institutional structure and incentive system. One should not underestimate these problems, however since the costs of marine debris are highly diffused through time and space.

CONCLUSION

Economic costs are lost benefits to society. Marine debris and lost fishing gear as a relatively small subset of that debris is but one of many environmental and social problems that the global community needs to consider. But while marine debris and lost fishing gear

may be relatively small in total, they may be substantial problems to particular localities. Such is the case of lost trawl nets in the Northwestern Hawaiian Islands. So the general conclusion is that to be effective, public policy on lost fishing gear must identify high net benefit points of intervention in the process by which fishing gear becomes lost and affects the broader society (and ecosystem). To implement this policy, it is critical for policy makers to reduce the divide between those who are downstream of lost fishing gear and those who are on the upstream side (i.e., fishermen). Involving the fishermen through a variety of institutional arrangements, whether they be economic incentives, joint educational panels, advisory groups, or simply the act of marine debris researchers walking the docks and talking to fishermen, will help insure that whatever is planned is actually implemented as intended and with the intended consequences.

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[1] The following comments do not necessarily reflect the opinions or policy of NMFS or NOAA.
[2] Kirkley J., and T. McConnell. 1994. International Marine Debris Conference.
[3] An idea confirmed by conversation with economists involved in the previous International Marine Debris Conference and through an Internet source search.
[4] Indeed the working paper written by Mark Minton for this conference does a good job of identifying fishing industry initiatives over the past five years.
[5] A colleague who has spent considerable time on commercial fishing vessels suggests that captains and crews generally do not discard fishing gear and shards willy-nilly overboard. After all, they too are aware of the specific costs of fouling their props and over-the-side gear in the marine debris. What frequently occurs, however is that gear shards may be stacked in a corner of the deck, perhaps in the ubiquitous plastic barrels and tubs that frequent fishing vessels, and during rough weather, these stacks and barrels break loose and are swept overboard.
[6] Direct costs are borne through fouled propellers on a variety of ocean craft.
[7] Clean Ships, Clean Ports, Clean Oceans (1995) raises a number of these points as well.
[8] The idea for these points was borrowed from Laska, 1997.
[9] Fishing vessel owners frequently attempt to minimize replacement costs by requiring crew to pay for lost gear out of their revenue share.
[10] The first monk seal I saw in the wild was sleeping on a marine debris dump by the harbor on Midway Island, presumably not the best place for young seals, but perhaps okay for an old seal.
[11] e.g., open access quotas vs. limited entry tradable quotas.

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NAVIGATIONAL HAZARDS AND RELATED PUBLIC SAFETY CONCERNS

ASSOCIATED WITH DERELICT FISHING GEAR AND MARINE DEBRIS

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IS THERE A PROBLEM?

When we hear the phrase “entanglement in marine debris” I would anticipate the majority of us picture in our minds aquatic marine life of some kind, fouled within derelict marine debris or fishing gear. Today, I would like to suggest we also consider that entanglement of propellers, rudders, jet intakes, and water intakes be taken seriously, and that some energy from this conference be channeled towards this less familiar entanglement topic.

AN ENCOUNTER WITH DERELICT FISHING GEAR

The following comes from an Albacore fishing vessel operator and one of his encounters with derelict fishing debris, April 2000, somewhere between 36° and 40° N Latitude and between 145° and 165° W Longitude.

“Last year was particularly bad for debris for the Albacore fleet. I imagine it was exacerbated by the La Niña current conditions that put us in the zone, although some previous years have been quite bad too. Several boats, including myself, encountered fouling en route from the West Coast (of the U.S.) to Hawai‘i in April, mainly pieces of light web; 1-1/12" mesh, black tarred twine like I'd imagine is used in sardine seines or aqua-culture. One boat encountered some hefty pieces of trawl web. In the area between 36° and 40° N and 145° and 165° W (just South of the Mendocino Fracture Zone) there were frequent encounters with the same web and also a lot of mono-filament gillnet-web, about 3" mesh. This is particularly hard to cut once it is wound tightly onto a propeller shaft! In one incident where a fishing partner was stopped dead, after he had almost drowned, we think it was bad air in his scuba tank, I ended up swimming over to finish the job. Amongst the mixture of web and rope were two banding straps such as one finds around frozen bait boxes, with Korean characters printed on them. Whilst it is always hard to get fishermen to volunteer information, it might be possible to informally compile debris encounter information in our fleet; if you have any particular suggestions, I would be happy to help.”

This encounter definitely raises concerned parties' interests and is an indicator that there may be a problem with derelict fishing gear as a navigation hazard and safety hazard.

THE “PROBLEM” MAY EXIST

This twin screw motor yacht caught a line during a routine trip for fuel. It wrecked propeller shafts, stern gear, and the flexible couplings on both engines. It was out of operation for a significant portion of a busy charter season. Drifting while disabled or having to go overboard with a knife to wrestle with a rope can have tragic consequences, even the most alert mariner cannot avoid submerged debris including lines or nets, especially at night. This device offers protection for vessels and their crew from a “stressful and potentially life threatening situation” as it is advertised.

Figure 1

Figure 1. Motor yacht in dry dock, propeller fouled by mooring line.

Figure 2

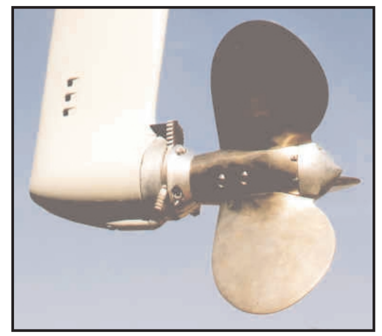


Figure 2. An installed line cutting device just forward of the propeller.

Figure 3

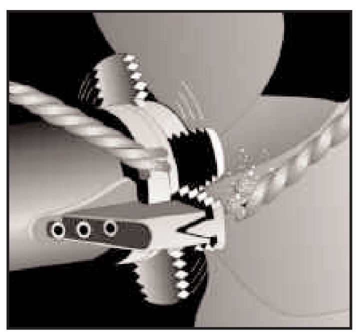


Figure 3. A diagram of an installed line-cutting device depicts the mechanics of how it is intended to function when in operation.

When industry designs devices such as these it is an indication that perhaps vessel fouling by marine debris is a problem worth researching.

MINIMAL PUBLISHED BACKGROUND

Studies on pelagic or offshore marine debris are not extensive but do exist in identifying both collection areas and types of debris. In the greater Pacific Ocean there are a few dated studies supporting the existence of increased marine debris north and northeast of the Hawaiian Archipelago. These studies are six years old and older.

Nets and lines that don't make landfall, accumulate in oceanic gyres and become the source of hazards to navigation and related public safety issues on the open ocean. Discussion in our research failed to uncover similar studies to identify the extent of this perceived problem. We found no historic statistics to aid us.

To help meet this gap or this draw for applicable datum sources, we fielded a survey to marine safety agencies and commercial entities in over thirty neighboring Pacific Ocean countries. We received replies from eleven countries.

HAZARD TO NAVIGATION SURVEY

This topic was in need of research. We chose to distribute a survey primarily to marine safety agencies within the Pacific region. We received replies from eleven Pacific Rim nations. Eight from the following countries were comprehensive enough to use in this report: Australia, New Zealand, Singapore, Philippines, Japan, China, Canada, and the United Sates.

Vessel classification societies, local insurance claim companies, Seattle Locks, Panama Canal, major marine insurance agencies, and Sea Grants were also given an opportunity to participate. This latter group accumulated only three responses and of the three responses, none had information to aid in the survey.

“Does marine debris pose a navigation hazard for commercial and recreational vessels in your nation's surrounding waters?” This was the first question presented in our survey. Scenarios that could qualify as navigational hazards and related public safety issues would include:

- Fouling or entanglement of a vessel's propeller, rudder, jet drives, or water intakes or restriction of vessel's ability to maneuver. If disabled or dead in the water with reduced visibility, such a vessel is in harms way from the track of a larger vessel, heavy weather, and increased sea states.

- Benthic or subsurface debris has the potential of fouling vessel anchors as well as equipment deployed from research vessels and fishing trawlers. These types of scenarios can put a vessel and its crew at risk.

Public safety scenarios that would most likely evolve from these encounters when vessels become disabled and remain so for extended periods due to distance, isolation, and communication complications and due to irreparable damage:

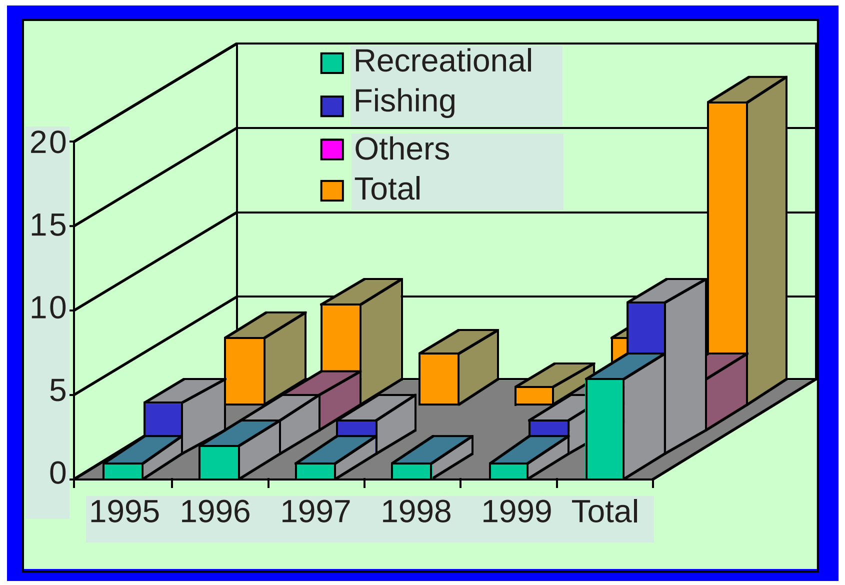
- May take on water around a damaged shaft seal.

- Must send an individual underwater to attempt to clear the debris. The sea state alone can make work in close proximity to a vessel's hull dangerous.

NAVIGATION CASES AND SURVEY RESULTS

From our eight solid responses many nations indicated two points: (1) the primary focus is to address this debris from an environmental hazard perspective and (2) many of our questions have not been tracked and were unknowns or best guesses. As a result, the perceived problem with hazards to navigation and safety remain an uncertain “yes” for most. The uncertainty is there because reporting mechanisms aren't established for mariners nor are recording mechanisms established for agencies and organizations.

JAPAN MARINE DEBRIS HAZARD TO NAVIGATION CASES



Japan, the country reporting the most data on this subject, and perhaps in the best position to answer this question from those countries and organizations surveyed, reports:

- The damage to the propeller related in all 18 cases represented in this graph.
- Australia reported five vessels and Canada's eastern shores reported fourteen cases on fishing gear. All other countries maintain no records.
- The cumulative damage for Japan, although incomplete, amounted to 6,700,000 Yen from 1995-1999.
- In 1992 Japan estimated their fishing industry spent $4.1 billion U.S. dollars in boat repairs resulting from damage caused by marine debris.
- Derelict fishing nets were stated as the most dangerous drifting objects for Japan.
- No specific action has been taken to address these eighteen cases from the past five years because the number of cases is not considered significant. However, Japan keeps a concerned watch on illegal ocean-dumping activity.

"What types of debris are responsible for hazard to navigation cases?" Our survey also asked this question.

NAVIGATIONAL HAZARDS AND
RELATED PUBLIC SAFETY CONCERNS
ASSOCIATED WITH DERELICT FISHING GEAR AND MARINE DEBRIS

- Japan reports - drifting fishing nets and ropes.
- Canada (West Coast) reports - lines, nets and logs. Logs become the major hazard of concern around British Columbia.
- Philippines report - plastic nets, bags, Styrofoam, rubber materials, logs, wooden ship remnants, other persistent debris.
- New Zealand reports - plastic strapping from fishing boats.
- United States - reports derelict fishing net and associated line, all sizes.

Other countries had insufficient information to report on this question.

ADDRESSING THE PROBLEM

- Continuous outreach and education are the focus or are a key interest for Australia, Philippines, New Zealand, and the United States, but not the only actions in place.
- The Philippine Coast Guard has led consistent cooperative government cleanup operations of affected waters.
- Hong Kong is establishing a sophisticated traffic management system to look after the inter-coastal traffic
- In Singapore, Flotsam retrieval craft are deployed, if necessary, on a daily basis to remove debris from the sea. Craft making the report are often asked to retrieve the debris as well.

Perhaps the larger question becomes, who has the responsibility for recovery of navigational hazards? The participants indicate that the coast guard has the lead in Canada's, Japan's, and the Philippine's waters. In Singapore the burden falls upon the port authority. In Australia and China, it is the maritime safety administrations. It is also suggested that none of these lead agencies take on the sole responsibility, so many seek outside assistance. Canada indicates that industry, in general, may not be as committed to debris control compared to the marine community.

RECOMMENDATIONS

- This field is in need of further research. Many past publications have suggested that vessel entanglement or propeller fouling is a field of concern in need of remedy or, at the least, a systematic study of not only issues related to public safety and navigational hazards, but to the economic costs associated with entanglement.

- It is suggested we, representatives of port countries, organizations, and industry collaborate and pursue the need for creation of an international offshore marine debris report form, and pursue incentive mechanisms for pelagic debris recovery and the systematic reporting and collection of this debris datum.

- We should consider seeking support from and engaging with established international committees.

- The International Maritime Organization (IMO) has a couple of outlets that may aide in this endeavor. As recently as March 2000, IMO's Legal Committee, 81st Session, met. Within this committee, the Draft Wreck Removal Convention was chartered with making provisions for international rules. More specifically, on the rights and obligations of states and ship owners in dealing with wrecks and drifting or sunken cargo that may pose a hazard to navigation and/or pose a threat to the marine environment.

- IMO also runs a spill and litter web page that is ideal for sharing information about your regional efforts.

ACKNOWLEDGMENTS

I would like to thank the planners of this gathering today: Mr. Daniel Ruseborn and Chris Woolaway under University of Hawai'i's SeaGrant Program for their resource support; the participants of our survey; Albacore fisherman Jeremy Brown from Bellingham, WA; National Marine Fisheries Service's Ray Boland and Chad Yoshinaga for their fine photos, some of which were used in this presentation; and to Mr. Paul Topping, Environment Canada's Marine Response Division, for background on Canada's offshore debris studies.

SOCIETY'S ROLE AND OBLIGATIONS AS STEWARDS OF THE OCEAN ENVIRONMENT

Honorable Daniel K. Inouye, United States Senator, Hawai'i

When this conference was first brought to my attention, I must confess that it took a few moments to register – "marine debris." That is a sophisticated way of saying rubbish in the ocean. Harmful rubbish and the need for trash collection. Now that registers and will resonate in our communities.

The task is daunting, but the message is simple: We must all work together to clean up, and pick up after ourselves to stem the tide of debris and destruction at sea.

Two decades ago, we did not know much about marine debris. This global conference reflects how much we have learned since then about the scale and importance of this problem. For example, we now know that the debris comes from all types of sources around the world, including ships and fishing vessels. But, it has also become clear that close to 80 percent of the rubbish in our oceans is washed, blown or dumped from shore. This debris moves through the world's oceans and into the most remote places, as well as onto our beaches.

While we have made some progress on reducing pollution from ships, a national or global solution to the marine debris problem is not yet within our grasp. Here in the Pacific alone we are faced with frightening statistics involving the entanglement and death of sea turtles, marine birds, whales, dolphins, fish, and seals, and the destruction of our precious coral reefs.

I am pleased to see representatives from across the Pacific, including Chile, Australia, Japan, Niue, Fiji and Micronesia, all coming together to develop a strategy to clean up our oceans and keep them clear of marine debris.

I am particularly pleased to learn about the efforts of the "Trash Busters," high school students who are committed to tackling this issue, and protecting our unique marine resources for future generations to enjoy. I commend these students for their dedication to this important cause.

I need not remind you, though, that marine debris is only one of a myriad of issues affecting our nation's coastal and ocean resources. We are faced with many challenges in the U.S. Exclusive Economic Zone (EEZ) and the global ocean on how best to fulfill our stewardship responsibilities. The key to effectively meeting these challenges is commitment–a commitment to do what is necessary. A commitment to make and then implement difficult decisions, domestically and internationally. The solution will not come from government action alone–each community, each person must also commit to making these tough decisions a part of everyday life.

Healthy oceans are critical to our quality of life. They provide food, medicine, recreation, and energy. We have heard the statistics:

Priscilla Billig, Marine Debris Communications Committee

United States Senator Daniel K. Inouye of HawaiÔi keynotes a luncheon session with an address on "Society's Role and Obligations as Stewards of the Ocean Environment".

- one out of every six jobs in the United States is marine related;
- one of every two Americans live within 50 miles of the coast;
- more than 180 million people visit the coast each year, generating 85 percent of all revenues from tourism in this country.

Our oceans are a vital environmental, economic, and recreational resource, and must be treated as a national priority.

In the 1960's we took a first, and revolutionary step toward focusing federal attention on our ocean and coastal resources. At the time we faced increasing pressures on these resources, but lacked any federal controls on coastal population growth, marine degradation, or overfishing. In 1966, the Congress created the Stratton Commission, which laid the foundation for U.S. ocean and coastal laws, policy and programs that have guided our stewardship for three decades.

The world has changed significantly since the days of the Stratton Commission. Ocean and coastal issues are gaining in importance, but they have not received the attention and priority they deserve. The ocean management regimes developed over the last 30 years need to be reexamined and revamped if we are to keep up with the changing times.

It saddens me to say that critical ocean conservation and management programs have not been adequately funded. Oceans have been treated as "second class citizens" compared with the more glamorous, such as the space program. We have invested billions of dollars to explore outer space, but have starved our missions to explore and understand our ocean space.

SOCIETY'S ROLE AND OBLIGATIONS AS
STEWARDS OF THE OCEAN ENVIRONMENT

Some have criticized the Stratton Commission, alleging that its recommendations led our nation down the path to overexploitation of marine resources. I disagree. But, rather than debating the wisdom of actions taken over 30 years ago, I believe it is a better use of our time and energy to focus on the next 30 years and beyond.

Regardless of one's perspective, one point is clear and unrefutable: the days of "doing business as usual" are over. It is time to put down our polarizing magnets and work together cooperatively, based on rational deliberation rather than emotional sound bites, to achieve our common goals.

As a nation, we must renew our commitment toward developing an integrated national ocean and coastal policy for the U.S. EEZ. I am pleased to report that we are on the cusp of a new era in ocean conservation and policy – the Congress recently passed the Oceans Act of 2000, which the President is expected to sign into law this week. Under the Oceans Act, the President, in consultation with the Congress, will appoint an independent Ocean Policy Commission to develop a national action plan for the 21st century to explore, protect, and better utilize our oceans and coasts.

As we work to get our domestic priorities in order, let us not forget that the ocean knows no boundaries. Many of the issues concerning our ocean environment can only be truly resolved through international cooperation.

There are many examples where the U.S., in an effort to set the example for the global community, will impose restrictions on domestic entities to protect its marine resources. This may sound like a good first step, but if the foreign governments and private entities do not follow suit, the U.S. could end up imposing restrictions on its own citizens, while those of other countries continue to do "business as usual."

One of the most emotional issues pending before the Congress relates to the banning of shark finning in the Pacific. This is a prime example of where U.S. policy must be supplemented by strong action to encourage foreign countries to adopt similar restrictions. Our action alone will not protect shark populations.

The protection of sea turtles is another example where international cooperation is critical to protecting these endangered resources. In the Pacific, only Hawaii-based fishermen are subject to severe prohibitions and restrictions, based on longline interactions with sea turtles. But these turtle populations interact with fleets from all nations throughout the Pacific Ocean. Fair questions have been raised as to whether these restrictions will actually protect the turtle population when the lion's share of the catch in the area is by unrestricted foreign fishing vessels.

Today, in Hawaii, an unprecedented partnership – the city, state and federal governments, private industry and non-governmental organizations, as well as international governments – are joining forces to remove derelict fishing gear in the Pacific. I have high hopes that the strategies developed from this collaboration will be replicated elsewhere.

I am convinced that it will be partnerships across government and private lines, and across domestic and international lines which will make the difference in the end. Might does not make right.

I submit to you that our nations must make a strong commitment to provide leadership in their own EEZs, as well as in the global ocean. Let us step forward to fulfill our responsibilities as stewards of our ocean environment. The distress call has been sent out. The S.O.S. – Save Our Seas.

A U.S. PERSPECTIVE ON MARPOL V: COMPLIANCE, ENFORCEMENT, AND IMPLEMENTATION

Paula S. Carroll, U.S. Coast Guard, Honolulu, Hawai'i

INTERNATIONAL CONVENTIONS

- Convention on the Intergovernmental Maritime Consultative Organization (CIMCO) (1948) - provided cooperation and opportunities among governments in regulating various shipping issues, including marine pollution. Established the Intergovernmental Maritime Consultative Organization, from which evolved the International Maritime Organization (IMO).

- Convention on the Prevention of Marine Pollution by Dumping of Wastes and other Matter (1972 London Dumping Convention) - regulated deliberate at-sea disposal of land-generated garbage by dumping of industrial and low-level radioactive wastes, and the at-sea incineration of industrial wastes. Later resolutions either called for a moratorium or ended the dumping and incineration practices. The 1996 Protocol replaced the 1972 Convention and is much more restrictive.

- International Convention for the Prevention of Pollution from Ships (APPS) (1973); modified in 1978 (MARPOL 73/78) - regulates discharge of non-landbased pollution. Annex V deals with different types of garbage and specifies the distances from land and the manner of disposal. Requirements are much more strict in designated "special areas" but the most important feature of the Annex is the complete ban imposed on the dumping of plastics. Dumping plastics overboard in any waters anywhere is illegal at anytime!

- Third United Nations Convention on the Law of the Sea (UNCLOS III) (1982) - a universally agreed upon set of rules governing uses of the oceans. UNCLOS III provides the ground rules for each nation's approach to controlling shipborne wastes and the extent to which another nation's right to establish its own approach must be respected.

DOMESTIC LAWS

- Marine Protection, Research, and Sanctuaries Act (U.S. Ocean Dumping Act) (1972) implements the London Dumping Convention. It requires the EPA to closely regulate all materials taken from land for the purpose of dumping. The EPA prohibits ocean disposal of plastic materials produced onshore.

- Clean Water Act (1972) prohibits the discharge of solids in effluent from point sources. Its primary objective is to restore and maintain the integrity of the nation's waters.

- The Marine Plastic Pollution Research and Control Act (MPPRCA) (1987) amends the Act to Prevent Pollution from Ships of 1982 (APPS) and implements Annex V of the Protocol of 1978 relating to the International Convention for the Prevention of Pollution from Ships, 1973/1978 (MARPOL 73/78). It prohibits the disposal of plastic materials produced during routine shipboard operations.

BARRIERS TO COMPLIANCE

Two major barriers to compliance are: (1) the difficulties mariners have when attempting to comply with Annex V, such as adequate shipboard garbage handling and storage procedures, and adequacy and affordability of port reception facilities, and (2) the ease with which violators can avoid detection.

COMPLIANCE CHALLENGES

Compliance rates fall if enforcing agencies are not adequately resourced and committed to enforcement. Compliance rates also depend on factors other than government enforcement, such as levels of industry environmental consciousness and the public's disdain for marine debris on beaches.

The Coast Guard reports that penalties are large enough to be considered significant, but the fact is, the likelihood of getting caught is low. However, if compliance were cheaper than violating, then the economic theory is that mariners would comply. Economic incentives are possibly the most powerful compliance mechanism for the commercial marine industry, but no one reward or punishment will bring all marine segments, commercial and recreational, into compliance with Annex V.

The National Research Council's report "Clean Ships, Clean Ports, Clean Oceans" in 1995 suggests system improvements that the government and the port could undertake to increase compliance.

Vessel Garbage Management

Government can:

- Assist with technology transfer for maximum information exchange among all maritime sectors, including the U.S. Navy, and evaluate technologies for on-board garbage handling and treatment. The U.S. Navy, required by domestic law to comply with MARPOL V, is the world leader in developing technology to deal with vessel-source pollution.
- Ensure on-board storage procedures are safe, and develop guidelines on ship sanitation.
- Offer financial assistance to achieve compliance.

Adequate Port-side Garbage Reception

Ports and government can:

- Strengthen recycling programs.
- Transfer oversight to EPA waste management experts and state governments assuring standards are met under the Resource Conservation and Recovery Act (PL 94-580) (RCRA).
- Better integrate Animal and Plant Health Inspection Service and Annex V regulations.
- Address who should pay for garbage services and how, for example, by standardizing fees. If disposal rates were uniform and affordable, then compliance would probably rise.

Barriers to U.S. Enforcement of Annex V

The Coast Guard's annual report to Congress in 1992 cited two distinct weaknesses in enforcement:

- The difficulty in obtaining eyewitness accounts
- The limitations imposed on the prosecution of foreign vessels.

Enforcement Challenges

Drafters of Annex V intended signatory nations to use methods to encourage compliance and enable enforcement. One of the most difficult aspects of enforcement is proving U.S. jurisdiction. Even if the master admits that all garbage, including plastics, is discharged at sea, it is sometimes impossible to prove that the discharge occurred within U.S. waters. If circumstantial evidence against foreign-flag vessels is the only indicator, then it is often too difficult to establish the disposal location to proceed. And additionally, when garbage washes ashore from a vessel, the enforcement agency must prove which mariner caused the discharge—a very difficult task.

The U.S. depends on reporting of incidents and vessel boardings in port more so than at-sea surveillance. At-sea infractions are almost impossible to detect and difficult to prosecute unless there are witnesses.

In 1992 the U.S. expanded its port state control policy whereby it pursues direct civil or criminal action in all cases where jurisdiction can be established. If there is evidence of a violation that took place within the EEZ, territorial sea or internal waters, then action is taken. Penalties have increased, with a criminal offense upgraded to a felony, and port officials are authorized to withhold clearance for departure.

Coast Guard policy states: "As of July 1992, the USCG began taking enforcement action under U.S. law, including referral to the DOJ, for all suspected MARPOL Annex V violations occurring within the U.S. EEZ. Prior to July, USCG policy had been to forward cases involving vessels of signatory nations (unless the violation occurred within three nautical miles) to the flag state administration for investigation and enforcement. The policy shift expanding coverage out to the EEZ became necessary because flag states were not taking adequate action in the cases forwarded by the U.S. Countries often failed to acknowledge receipt of the cases and many took little if any legal action against suspected vessels."

Current Coast Guard procedures for enforcing MARPOL V include:

- Animal and Plant Health Inspection Service (APHIS) inspectors report suspected Annex V violations to the Captain of the Port and, if resources permit, the Coast Guard also boards suspected vessels.
- At-sea boardings for Annex V compliance are conducted as resources permit, in conjunction with other routine boarding activities.
- In-port boardings for Annex V compliance are conducted as part of the Coast Guard's vessel monitoring program (port state control boardings or U.S. vessel inspections). Personnel verify APHIS inspections by sighting the PPQ Form 288 on board, and conduct a follow-up Coast Guard check for compliance with Annex V.
- If an APHIS inspection has not been conducted, particular attention should be given to shipboard garbage handling practices, use of plastics and any evidence of possible illegal discharges. The Coast Guard believes that vessel operators will prioritize Annex V compliance based on the level of interest expressed by the Coast Guard, the enforcement agency.

There has been a dramatic decline in MARPOL violations from 1993 to 1999. It is unclear if this decrease is a trend in compliance or an indicator of reduced enforcement. It is likely a combination of both. Compliance positives include increased public awareness, improved reception facilities in U.S. ports, use of incinerators, and the reduction/reuse of packaging. On the other hand, garbage does not get a public or government spotlight in comparison to oil or hazardous material issues.

The National Research Council suggests several methods to improve enforcement:

- Fully exercise port state control.
- Issue tickets in civil cases especially in the fishing and recreation sectors.
- Require ports provide receipts for off-loaded garbage and compare these to vessel logs.
- Enlist the assistance of other agencies (i.e., NMFS, MMS, State Marine Police) in reporting violations.
- Encourage ship operators to report inadequate reception facilities at ports.
- Increase public awareness to report illegal disposal through educational programs.
- Receive reports from all sources - private citizens, interested parties, environmental groups, other federal agencies, state and local agencies.

Barriers to Implementation

The two greatest obstacles to implementation are: the undeveloped nature of comprehensive data collection and monitoring programs to establish baselines, and the lack of national leadership to coordinate all aspects of MARPOL V compliance, enforcement, and implementation.

Implementation Challenges

Implementation cannot rely solely on the government's ability to identify violators and enforce the law. Monitoring debris is an important aspect in determining practical interventions, but it is not well defined. There are systematic efforts to monitor, but the results are not detecting clear trends. Additionally, considerable amounts of garbage are generated and discarded by mariners, but the amounts are only estimated. The amount of garbage is just one factor related to garbage sources. Others of importance include the number of vessels (which reflect point source generation), the maritime sector, voyage duration, and the nature of the garbage. Plastic is a primary concern. Not only is it persistent, but abundant and the disposal of plastics is causing considerable harm. Environmental monitoring could be designed to determine fluxes of plastics through the marine environment as a function of time. This could be expanded to include fishing gear.

Another challenge is that data are available, but not in government-wide format. Agencies collect their own data and the systems are not compatible from agency to agency, plus the emphasis on data collection is sporadic. A joint CG/APHIS system could possibly help determine the direction of monitoring and enforcement.

In order to determine which interventions are effective and to enhance the scientific understanding of oceans, progress in implementation could be measured with comprehensive data collected over time on:

- Numbers of vessels discharging garbage at ports.
- Amounts of garbage discharged.
- Numbers of complaints about garbage reception facilities.
- Numbers of repeat violations by vessels and ports.

Better oceanographic and satellite data have improved the understanding of ocean currents and marine dynamics. As a result, the arbitrary disposal limits (12, 25, 200 miles) may not protect coastal areas. To allow dumping of some wastes at a "safe" distance from shore is clearly ineffective, since these wastes usually end up on beaches or remain at sea, posing a threat to aquatic animals and birds. Additionally, zero-discharge rules do not protect special areas fully. Debris can be transported over long distances and legally discharged garbage can drift into special areas. It is highly migratory.

Education is an effective intervention against the problem of vessel garbage, but it is not enough. The corporate culture perspective suggests crew behavior that reflects the values of employer corporations. Education and training efforts should target senior managers to foster organizational change. Another tack is that Congress could charter a foundation to coordinate a long-term, national program devoted to Annex V education and training.

Strong national leadership is critical to successful Annex V implementation. No lead agency exists to: coordinate the overall effort of developing on-board technology; monitor the adequacy of port reception facilities; inform marine sectors of compliance methods; or enforce the law. The NRC report recommends the formation of a national commission that could coordinate federal agency efforts, serve as the focal point for U.S. leadership worldwide, and increase standards of performance.

Waste reduction could be introduced as a management option. Most efforts (economic incentives, education, enforcement) have been interventions carried out after packaging and other items of non-degradable materials are already on board, versus proactive efforts of reducing waste generation before through source reduction of plastic packaging and the use of biodegradable containers.

Federal control capabilities vary by maritime sectors. The Coast Guard has direct regulation of cargo and passenger fleets but the fishing industry is less regulated, down to little direct control of recreational boaters. Interventions must be appropriate to the particular maritime sector and sustainable within resource limitations. No single implementation approach works across the board.

The following is a look at existing or recommended interventions for three sectors: (1) fisheries, (2) cargo vessels, and (3) the cruise industry.

Fisheries:
- Some have onboard observers, others assess catch at the pier. In both cases a survey mechanism could be implemented to gain information on the feasibility of net and gear disposal alternatives.
- Employee complaints and peer pressure offer indirect control.
- Port reception facilities that are considered inadequate for all garbage generated can be improved. The government may offer to subsidize modification costs, or guarantee loans for facility construction, or classify costs of port reception facilities as pollution-control devices for bond underwriting purposes.
- Technological interventions such as compactors, shredders and incinerators need to be tailored to conditions on fishing vessels with regards to size, placement, etc.

- Fishing organizations may request establishment of reception facilities sized to local needs.
- Education to encourage voluntary compliance must continue.
- Enforcement, including vigorous prosecution and significant penalties, is important. If objectives are not met through voluntary compliance, then federal agencies should focus their enforcement resources on the most effective strategies (i.e., NMFS observers monitoring for Annex V violations in addition to their regular duties and requiring the reporting of fishing gear losses).
- International agreements between nations should encourage and require Annex V compliance.
- Develop interventions that encourage the return of used fishing gear to shore by requiring deposits on nets and lines, and promote recycling of fishing gear.

Cargo Ships:
- Ports seldom record garbage transactions.
- The Coast Guard exercises port state enforcement by directing U.S. action against more foreign-flag violators and fewer cases are being referred to flag states.
- Develop a possible international requirement that flag states issue certificates confirming ships' waste management systems meet or exceed some minimum criteria. IMO would issue these like IOPP certificates. A comprehensive capability to manage wastes would exempt vessels from off-loading at U.S. ports.
- The Coast Guard exerts control over public ports and operators of large private terminals through the COA program, but cost and convenience levels are not regulated.
- Alternative packaging and storage systems need to be developed that minimize use of plastics.

- Appropriate garbage treatment equipment could be designed for new ships and purchased, developed, and retrofitted on existing ships.
- Offer economic incentives to vessel owner/operators (i.e., return monies from recycling to the crews and revamp the inconsistent fee structure for garbage disposal).

Passenger Cruise Ships:
- The threat of public embarrassment over citizen reports of violations serves as an effective deterrent.
- A major barrier to compliance lies in port reception facilities, their adequacy, and convenience.
- Education of crew and passengers is a key intervention.

So what should we do to enhance compliance, enforcement, and implementation?

- Should we increase the effectiveness of the treaties by expanding existing enforcement agencies?
- How do we reduce the source or improve on-board storage?
- How do we encourage shoreside disposal/recycling of general vessel garbage and fishing gear?
- Do we increase port state control measures to ensure international compliance with MARPOL?
- Should we increase public education efforts targeting boaters, the ports, industry, and the public?
- Do we need more special areas?
- Should we increase technology sharing between communities and enhance garbage management systems?
- Within the Pacific region, who are the national agencies responsible for domestic and international implementation of MARPOL V activities?

These are issues for this conference. There is work to be done. The challenge for the participants is to produce an outcome-based action plan to effectively resolve these issues. If we leave here without positive action in this regard, then our time, in large degree, will have been wasted.

ACKNOWLEDGMENTS

I wish to acknowledge Ray Boland of the National Marine Fisheries Service for the background slide on underwater marine debris. I also credit the National Research Council's 1995 report for several of the ideas presented in this paper. I searched the web for current information but the NRC report was by far my most comprehensive source.

DERELICT FISHING GEAR MONITORING AND REMOVAL

Mary Donohue, Marine Debris Coordinator, University of Hawai'i, Joint Institute for Marine and Atmospheric Research and National Marine Fisheries Service, Hawai'i

INTRODUCTION

I want to thank the conference for inviting me to speak here today. I am going to be talking about derelict fishing gear—monitoring and removal. In fact, the majority of efforts aimed at removing derelict fishing gear are done in conjunction with monitoring or assessment investigations, and the mitigation to date has relied primarily on marine debris removal.

The methods that I'm going to describe today include: beach surveys, which may or may not have a removal component to them; shipboard sighting surveys, which almost never have a marine debris removal component; shipboard trawl surveys, which may or may not include debris removal; and diving surveys. I'll spend the most amount of time describing a diving project that the National Marine Fisheries Service, Honolulu Laboratory, in cooperation with a multitude of partners, is conducting in the Northwestern Hawaiian Islands to survey and remove derelict fishing gear from fragile coral reef ecosystems. Lastly, I'll touch upon the potential utility of remote sensing to both survey and increase the effectiveness of marine debris removal efforts.

BEACH SURVEYS

Beach surveys are really the most cost effective and widespread effort to remove marine debris from the littoral or shoreline environment, and the Center for Marine Conservation and other organizations have been extremely successfully in orchestrating them. These large-scale efforts usually are comprised of primarily volunteer personnel. They can be either beach-focused or ocean-focused (Ribic et al.), the latter of which is useful in derelict fishing gear monitoring. Ocean-focused surveys use debris washed ashore as an indication of the debris that's discarded or lost at sea.

A clearly stated goal is advantageous in these programs which not only allows the comparison between years of the same program, but also between various investigations. A rigorous sampling design is also advantageous when possible, for the same inter-annual and inter-investigation comparison. These surveys can document and remove small to large debris items, and information on type and accumulation rate can be generated. And, as I mentioned, most often removal is a large component of these types of efforts.

There are slightly different efforts conducted on some remote islands. They usually target larger debris items. For example, derelict fishing gear fragments like you see here washed ashore at French Frigate Shoals in the Northwestern Hawaiian Islands. These efforts are often carried out by governmental agencies and they, as well, require personnel on the beach. They are usually ocean-focused and, as in the former example, a rigorous experimental and sampling design is advantageous for comparisons down the road. In these efforts, medium to large debris items can be documented, type and accumulation rate generated, and removal may or may not be included depending on the objectives of the study.

Some examples of these types of remote island surveys include the work of Theodore Merrill and Scott Johnson, who worked in the Aleutian Islands in Southeast Alaska. They monitored derelict trawl net fragments washing up on these beaches for a number of years. Also included is the work of John Henderson and colleagues at the National Marine Fisheries Service Honolulu Laboratory. John has been monitoring entangling trawl net fragments and other entangling fishing gear that washes ashore in the Northwestern Hawaiian Islands. There is other work as well. Professor Daniel Torres has been monitoring derelict fishing gear fragments in Cape Shirreff, Antarctica. These have been very fruitful studies.

Looking at debris that has washed ashore doesn't always give us accurate information on the proportion or types of debris that are discarded or lost. There can be differential fates associated with varied debris types. Some debris may degrade more readily in the ocean. While beach surveys have been very successful efforts, they don't always give an accurate picture of the debris population at sea. I'm going to cover alternative methods that can address that.

SHIPBOARD SIGHTING SURVEYS

To get information on open-ocean or pelagic debris one can use shipboard sighting surveys. These are just about exactly what they sound like. One needs, obviously, a ship which can either be a dedicated platform chartered for the sole purpose of conducting observational transects for debris, but more often, an opportunistic vessel is used. That is, observers are put on vessels conducting other business.

Shipboard sighting surveys can document medium to extra large debris items and information on type and density can be generated. It is difficult and not customary to remove debris during these surveys. As one can imagine, the ship is steaming along the transect line which is not going to tell us about the debris mired or rusting on the sea floor. Nevertheless, numerous sighting surveys have been conducted primarily by Japanese researchers in the North Pacific and have given us some very valuable information on pelagic derelict fishing gear distribution in that region.

SHIPBOARD TRAWL SURVEYS

To examine debris resting on the sea floor, some investigators have employed shipboard trawl surveys. This is basically just trawling for debris rather than fish. Again, one needs a ship platform. This can be dedicated or opportunistic as we discussed for the sighting surveys. Opportunistic may mean that the ship is conducting trawl operations to monitor

fishery stocks or conducting active fishing, and the debris that is captured in the trawl is documented. Large to extra large debris items can be recovered in this way and the distribution of the debris documented, as well as information on the amount of debris that comes up per trawl swath. Debris captured in the trawls is effectively removed, although there have been cases of the debris then being tossed back overboard after documentation. Trawl surveys, however, are not a method that I can envision being used for large-scale benthic marine debris cleanups. Furthermore, this method cannot be used in very shallow water, on steep sea slopes or sea canyons, on rocky or coral reef environments where damage to the substrate could occur, or where nets can be lost.

DIVING SURVEYS

That brings us to diving surveys for marine debris removal. I'm not going to discuss the use of manned submersibles or remotely operated vehicles today, although I think they warrant further investigation. Today, I'm going to talk about using human divers to survey for and remove derelict fishing gear. Divers can find medium to extra large debris items. They can work in very shallow reefs and on steep sea slopes. Distribution, density, and information on type of debris can be readily obtained. I'll also demonstrate to you that debris removal can be carried out very effectively using divers.

MULTI-AGENCY MARINE DEBRIS REMOVAL

In the remainder of my talk I am going to primarily focus on and share with you information on a multi-agency marine debris removal and survey project led by the National Marine Fisheries Service, Honolulu Laboratory in the Northwestern Hawaiian Islands. This is a project that has succeeded because of the commitment and support of a multitude of partners that span the private, public, and industry sectors of our society.

The Northwestern Hawaiian Islands, as expected, lie northwest of the main Hawaiian Islands. The work that I'm going to describe today has been completed at French Frigate Shoals, Lisianski Island, Pearl and Hermes Atoll, and Midway Atoll. We have plans this Fall to investigate Kure Atoll as well. One of the reasons this area is so critical and important to investigate is that, in fact, the Northwestern Hawaiian Islands comprise the greatest amount of coral reefs by area in the U.S.—69%.

Not only are the coral reef resources incredibly valuable and precious in this area, but we know that derelict fishing gear has negative consequences on this ecosystem. These include wildlife entanglement, including threatened and endangered species as well as damage to the coral reef substrate itself. We suspect that there might be ecological consequences because of substrate disturbance caused by derelict gear scouring and abrading reefs as it moves through the ecosystem. Also of concern is the potential of derelict fishing gear to act as a vector for the introduction of alien species.

The umbrella objectives of this multi-agency partnership are four-fold: (1) continue and expand interagency partnerships addressing debris mitigation efforts, and to date, this is debris removal; (2) refine and implement procedures for expanded cleanup efforts; (3) develop expertise for net identification; and (4) expand our accumulation rate and impact study sites, which we are presently doing.

So, how did we do this? It's quite intense logistically. This last Fall we focused on Lisianski Island and Pearl and Hermes Atoll. We had the support of two ship platforms, the United States Coast Guard Cutter Walnut and the NOAA R/V ship Townsend Cromwell. We had 14 United States Coast Guard divers, small boats and inflatable barges, scientists who could analyze the derelict fishing gear recovered, and 18 specialized large rubbish bins donated by Browning and Ferris Industries, Inc. The bins allowed us to store recovered debris safely on the deck of the Coast Guard Cutter enroute to Honolulu for disposal. The ships spent just shy of a month on site at the islands.

What we did is put divers in the water behind these small boats and towed the divers on manta boards. Divers are snorkeling, not using compressed air, and the divers are towed in a parallel track search pattern documented by GPS. You can see a boat towing the divers; they happen to be at the surface at that point, and you can see what it's like under water at the left there. Once debris is located, information is taken on the size, type, and construction of the debris. The location is documented using GPS and then the divers go to work carefully cutting the debris from the coral substrate. This is a fairly surgical procedure, the divers cut the debris so as to not damage additional coral and not injure other divers around them.

Once the debris is cut loose from the substrate it is loaded into small boats by hand. These boats then transfer their debris loads to the large support ships, primarily the Coast Guard Cutter, whereupon it is craned aboard the deck. Once onboard the support ship(s), the boatloads of debris, which often consist of numerous types of debris entangled with one another, are characterized. The debris is weighed in total and then the conglomerates are separated by type. Types of net recorded are monofilament gillnet, multifilament gillnet, seine net, knotless trawl net, and knotted trawl net. Specific measurements are noted on each type of net present such as eye size, twine diameter, and the like, which we hope proves useful in identifying source fisheries. Coral rubble is removed from the nets, and miscellaneous maritime line or rope is also separated out. Lastly, all of the various components are weighed individually.

Since this work began in 1996, over 35,000 kg of debris have been removed using these methods. This total includes approximately 4,500 kg of debris removed by the National Marine Fisheries Service Honolulu Laboratory in 1996 and 1997 from French Frigate Shoals

and Pearl and Hermes Atoll. This preliminary work spoke to the scope of this problem. In 1998 the National Marine Fisheries Service Honolulu Laboratory, in hopes of increasing effectiveness and working cooperatively with other agencies and organizations, formed a multi-agency partnership to tackle the lethal problem of derelict fishing gear in the Northwestern Hawaiian Islands. During the first year of the partnership's activities, an additional 7,500 kg of lost or discarded fishing gear was removed from the coral reefs of French Frigate Shoals. This last year's effort, Fall 1999, focused on Lisianski Island, Pearl and Hermes Atoll, and Midway Atoll and recovered just over 23,200 kg of derelict fishing gear.

Our future plans for the multi-agency partnership include expanding international participation in cleanup and source identification efforts, revisiting cleaned sites to monitor accumulation rates, expanding our reference collection for source identification, and lastly, investigating the usefulness of remote sensing for increased operational efficiency. The last topic I'll discuss today is the potential utility of remote sensing to marine debris mitigation.

The remote sensing data I'll discuss here are almost exclusively satellite data. The two types of satellite data I'll touch upon today include: (1) oceanographic data, and (2) imaging data coupled with Global Information Systems (GIS). Oceanographic data tell us that the Hawaiian Archipelago is subject to debris set adrift throughout the North Pacific Ocean. In 1994 a Japanese researcher named Kubota, using a computer simulation model, explained how debris set adrift throughout the North Pacific is concentrated in an oceanic convergence zone near the Hawaiian Islands. Kubota argued this convergence zone is a result of synergistic oceanic surface currents, including the Ekman convergence zone, due to westerly and trade winds, geostrophic currents, and Ekman drift resulting from the atmospheric North Pacific subtropical high. More recently, Rusty Brainard and Dave Foley at the National Marine Fisheries Service Honolulu Laboratory have mapped this convergence zone using instruments mounted on satellites, producing results such as the map you see here. Brainard and Foley have confirmed the presence of a dynamic convergence zone which seasonally overlays the Hawaiian Archipelago. This convergence of oceanic waters, and the floating debris it carries, has been documented to exist further south in years characterized by El Niño events. Oceanographic data can describe where marine debris is most likely to be found, but it cannot locate actual debris items, say for at-sea recovery before the debris has an opportunity to encounter protected coral reefs and associated wildlife. To identify actual locations of marine debris remotely, the combination of satellite imaging and GIS may prove fruitful.

Recently, the U.S. NOAA Fisheries and U.S. NOAA Coastwatch have been investigating the use of satellite imaging to map and assess coral reef habitat in the Northwestern Hawaiian Islands. This imaging may also prove useful in mapping derelict fishing gear in this habitat. IKONOS satellite imagery, generated from a privately owned and operated satellite, is being used to generate base maps, and with proper groundtruthing, may be able to identify derelict nets of approximately 2 m in diameter. While this imaging is currently very expensive for large scale marine debris mapping, the IKONOS imaging could potentially be used to generate a "spectral library" of net types which might then be able to be identified in-situ with less expensive satellite images. ASTER (Advanced Spaceborne Thermal Emission and Reflectance Radiometer) imagery may be useful in this regard. This instrument is flying on the Terra platform as part of NASA's Earth Observing System. ASTER imagery may have too course a resolution ability to identify derelict nets, but a spectral library developed using IKONOS imagery should be used to determine if reflectance signatures of nets can be identified in ASTER imagery, which is available at no charge. A final source of imagery may be the AVIRIS (Airborne Visible InfraRed Imaging Spectrometer) imager. This is a unique optical sensor that flies aboard a NASA ER-2 airplane approximately 20 km above sea level providing a ground resolution of 20 m. The main advantage of AVIRIS is that it is a true hyperspectral instrument that allows very precise spectral segregation, to possibly identify the reflectance signatures of derelict fishing nets. The disadvantages include the relative coarse resolution and the cost of the imagery for those other than co-principle investigators. The success of these methods will depend on the ability to correctly classify the spectral signatures of the nets and to be able to distinguish the nets from their surroundings. Since proper classification depends on verification through in-situ fieldwork; precise field mapping is a key component to the success or failure of such initiatives.

CONCLUSION

To conclude, numerous methods exist to monitor and remove derelict fishing gear. The appropriateness and effectiveness of these methods is dependent on such variables as the objective of the study, the substrate on which the marine debris to be removed is located, and the amount of funding available to execute the effort. To maximize the effectiveness of such endeavors, emerging technologies must be used in conjunction with the continued refinement of classic methods. Further, I hope that I've convinced you that diving studies for marine debris documentation are an option for areas inaccessible to other survey methods. Lastly, that divers can remove derelict fishing gear from fragile habitat with little additional anthropogenic damage, and that the use of divers for large-scale derelict fishing gear survey and removal efforts is feasible. Thank you.

- Transcribed from a speech given August 7, 2000.

SURFACE CURRENT CONCENTRATION OF FLOATING MARINE DEBRIS IN THE NORTH PACIFIC OCEAN: 12-YEAR OSCURS MODEL EXPERIMENTS

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ABSTRACT

To investigate the dispersal of marine debris (i.e., derelict fishing nets) by surface currents in the North Pacific Ocean, numerical experiments were performed using the Ocean Surface Current Simulator (OSCURS). For these experiments, 113 drifters were seeded uniformly over the North Pacific and their movements were followed day-by-day for two 12-year intervals beginning in 1965 and 1977. The number of drifters located within each of 12 areas were summed at yearly intervals. As time progressed, winds and currents preferentially accumulated the drifters in four areas comprising 28% of the initial grid area (113 cells, each 5° by 10° of latitude and longitude, respectively). The total number of drifters in these areas rose exponentially with an average gathering time-constant of 2.8 years, starting from 28%, reaching equilibrium (73%) after approximately two time-constants of the subtropical gyre (6 years). Statistical fits to the accumulations beginning in 1965 and 1977 embracing the 1977 North Pacific regime shift gave nearly the same parameters.

In the four accumulation areas, tabulations of marine debris surveys in 5° latitude by 10° longitude squares showed 52% of the debris, a difference attributable to continuous versus OSCURS' instantaneous releases.

BACKGROUND

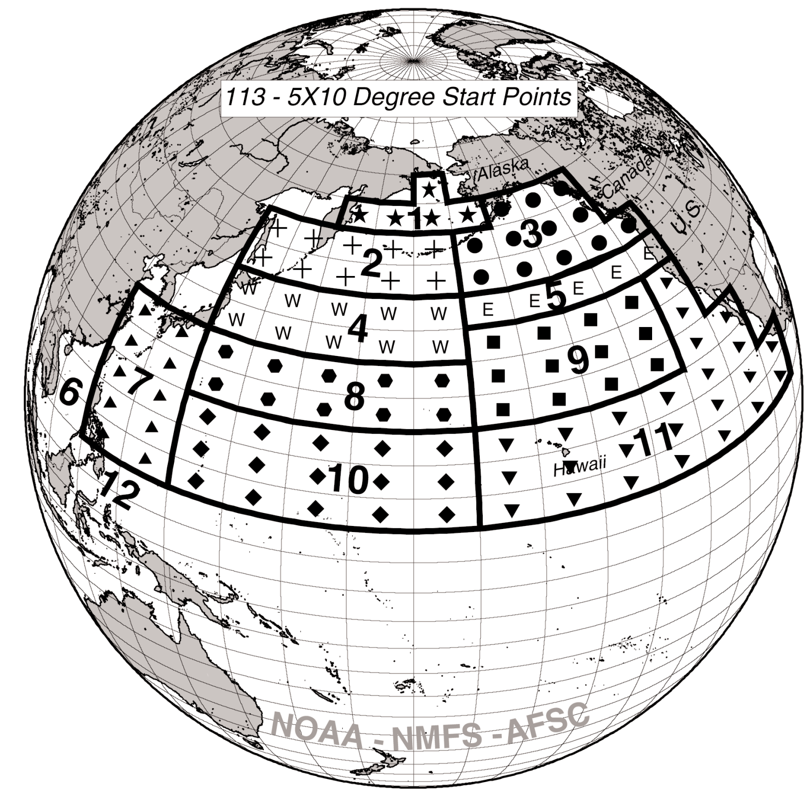
The accumulation of floating marine debris in the North Pacific Ocean north of the Hawaiian Islands was investigated by Kubota (1994) using Ekman drift, Stokes drift, and geostrophic currents. We carry this study a step forward by computing the time evolution of the Ekman convergence and simulating trajectories of drifting debris for 12 years using the Ocean Surface Current Simulator (OSCURS) numerical model.

The OSCURS model adds water movement to the available indices of atmospheric or oceanic variability (e.g., Southern Oscillation Index, Pacific Decadal Oscillation, North Pacific index, sea surface temperature, sea level, Upwelling Index). Computations are done on OSCURS' 92 x 180 grid that covers the ocean area from the U.S. West Coast to China, and from 10° to 66° N (Bering Strait). By generating current vectors, OSCURS integrates the effects of atmospheric forcing on the ocean surface (mixed layer) over the time of drift. Following the methods of Larson and Laevastu (1972), OSCURS adds 2 surface current vector fields; the daily wind-driven surface current vector field and a constant long-term mean geostrophic current field (0/2000 db; see Ingraham and Miyahara, 1988). The daily surface currents are computed from gridded daily sea level pressures by applying empirical functions on a 90 km grid over the North Pacific Ocean; the geostrophic current field is computed from long-term temperature and salinity fields. The empirical function for current speed is c (cm/sec) = 5.8 (w1/2) (Larson and Laevastu, 1972), where w is the wind speed (m/sec), and the empirical function for the angle to the right of the wind increases from 20° to 31° with increasing wind speed (Weber, 1983). The current speed coefficient and angle of deflection to the right of the wind were previously tuned to reproduce 3 month-long trajectories of satellite-tracked drifters in the Gulf of Alaska (drogued at 20 m; Ingraham and Miyahara, 1989). The trajectories are also subject to a slip boundary condition at the coast, and are moved along by only the long-shore component of the wind plus the geostrophic current extrapolated to near shore. For further information, see the link to OSCURS on the Alaska Fisheries Science Center's web site at ***www.refm.noaa.gov/docs/oscurs/get_to_know.htm***.

EXPERIMENT

To investigate the time scales associated with the debris surveys of 1986–91 reported by Matsumura and Nasu (1997), we seeded drifters within the OSCURS grid. One particle was released in each of the 5° latitude by 10° longitude squares used to tabulate the referenced marine debris sightings. Figure 1 shows the locations of the 113 particles released on January 1, 1965 and January 1, 1977.

Figure 1



Starting locations (10 symbols, 10 areas) for the 113 drifters released in the OSCURS simulations and locations of the 12 summation areas by number. Heavier lines show the 10 start areas (1–5 and 7–11) within the grid and 2 accumulation areas (6 and 12) outside the grid. These are the 12 areas in which the drifter count was tabulated yearly; note Areas 6 and 12 are out of the domain and start with zero while the total number in all 12 areas always sums up to 113.

With this experiment we sought answers to three questions:

1. Where would the drifters end up after elapsed times of 1 to 12 years? We ended the experiment after 12 years, time for the subpolar and subtropical gyres to rotate at least twice.

2. How fast do drifters accumulate? To summarize the results, we tabulated the number of particles yearly within 12 areas.

3. Did the results vary if the drifters were released in differing decadal climate regimes? To investigate this aspect, the particles were started before and after the 1977 North Pacific regime shift: 1965–1976 and 1977–1988.

RESULTS

Where do the drifters from each area go?

Figure 2 shows sample 12-year OSCURS' trajectories for the 5 drifters released in 1965 and 1977 in the Bering Sea, Area 1. The trajectories from the other 9 areas are shown in the appendix.

In general, these simulations show the Subarctic Region (north of 42° N) is an area of net loss and the Subtropic Region (south of 42° N) is generally an area of net accumulation. The greatest accumulation occurs in areas 7, 8, and 9 between 25° and 35° N along longitudes 120° E to 130° W. There are many interesting features, some shown for the first time, in the patterns of these long-term drift trajectories.

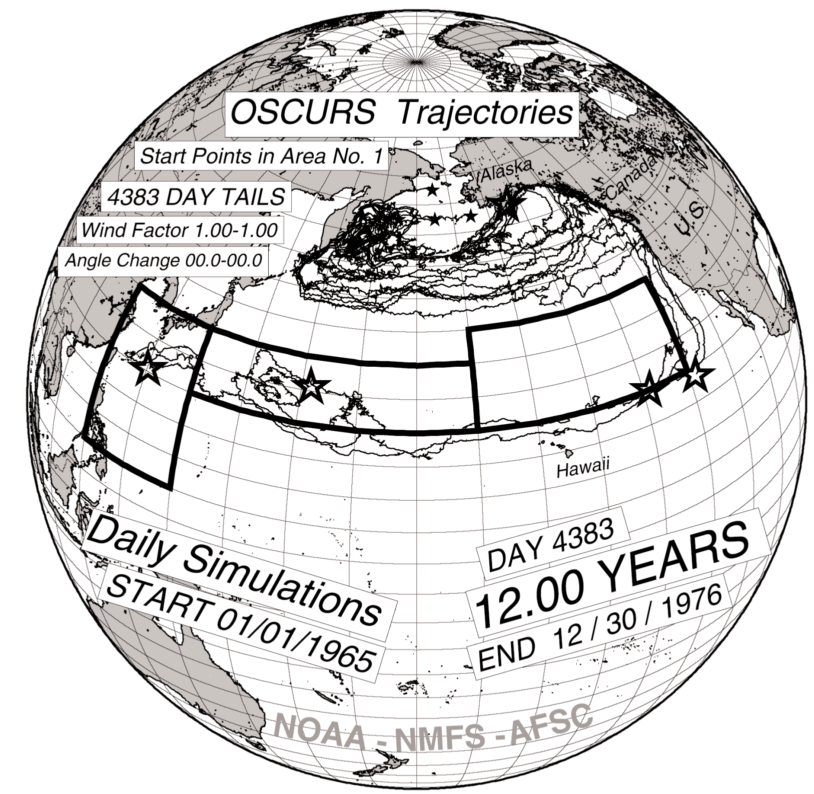
Five drifters started from Area 1 on January 1, 1977 (figure 2a) and moved quickly westward across the Bering Sea, then southward in the East Kamchatka Current. They then turned eastward for 2 years in the West Wind Drift, then separated in the divergence off the Washington coast. Two headed north around the Gulf of Alaska Gyre in the Alaska Current, then southwestward in the Alaskan Stream, and 3 headed south in the California Current, then to Hawai'i and the Philippines in the North Equatorial Current and into the "Western Garbage Patch". The same features were present in drifters from Area 1 that started about a decade earlier on January 1, 1965 (figure 2b) but a few more recirculated northward around the Gulf of Alaska prior to the 1977 regime shift.

Descriptions for the remaining drifters started in 1977 in Subarctic areas 2, 3, 4, and 5 and the Subtropic areas 7, 8, 9, 10, and 11, are as follows (see appendix for figures).

Ten drifters from Area 2 (Western Subarctic) and 12 drifters from Area 3 (Gulf of Alaska) also showed similar behavior. They started downstream of the Bering Sea drifters. One notable difference was the greater number of drifters from the western side that leaked to the south in the California Current compared to the apparently longer residence time for those released in the Gulf of Alaska.

SURFACE CURRENT CONCENTRATION OF FLOATING MARINE DEBRIS IN THE NORTH PACIFIC OCEAN:
12-YEAR OSCURS MODEL EXPERIMENTS

Figure 2(a)

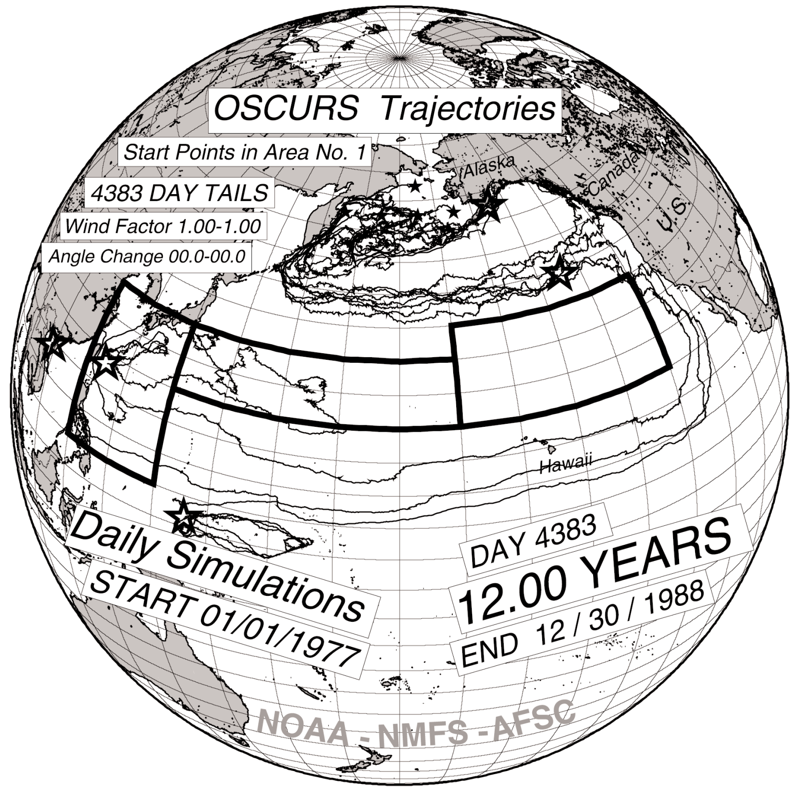


BERING SEA: 1965–1976

Figure 2(a). OSCURS trajectories (thin black lines) for 5 drifters starting in Area 1 (the Bering Sea) lasting 12 years (4383 days) beginning January 1, 1965 (drifter start points are solid stars and end points are large open stars).

Ten drifters from Area 4 (Western West Wind Drift) and 5 from Area 5 (Eastern West Wind Drift) drifted primarily southward in the California Current when they reached the North American coast. They finally accumulated within the garbage patch Areas 7, 8, and 9 or left the grid toward southeast Asia (Area 6 or 12). None of the 10 drifters from Area 4 went northward; 1 of 5 drifters from Area 5 drifted north. There is a tendency for drifters released in the eastern side of the West Wind Drift to be retained within the Subarctic Region.

Figure 2(b)



BERING SEA: 1977–1988

Figure 2(b). OSCURS trajectories (thin black lines) for the drifters starting in Area 1 (the Bering Sea) lasting 12 years (4383 days) beginning January 1, 1977 (drifter start points are solid stars and end points are larger open stars).

A major feature appears when examining the drifters released within the Subtropic Region (Areas 7, 8, 9, 10, and 11). Drifters seeded in Areas 7, 8, and 9 all remained within these 3 areas or took the westward exit from the grid to the China coast, where they do not rejoin the North Pacific circulation due to predominant year-round easterly winds. Ten drifters from Area 7 (Western Subtropic) drifted eastward at first then recirculated to the south and west tending to stay in the west or the Western Garbage Patch. Only a few escaped the grid to the west and south, but none leaked northward to the Subarctic. Ten Area 8 (Western Garbage Patch) drifters circulate slowly clockwise distributing themselves fairly evenly east-west and again none leaked to the Subarctic. Twelve drifters from Area 9 (Eastern Garbage Patch) seemed to have a long residence time there before repeating the pattern of the Area 8 drifters. Long-term drifters appeared to reside longer on the same side of the Subtropic North Pacific Ocean in which they originated.

Drifters from Area 10 (Western Trade Winds) swiftly exited westward to the Philippines where they dispersed off the grid to China or to the north and eastward in the Kuroshio Current. From there, they proceeded slowly eastward to the Western or Eastern Garbage Patch or recirculated in the Kuroshio Garbage Patch. One of the 15 drifters escaped to the north and traveled around the Gulf of Alaska Gyre.

The drifters from Area 11 (Eastern Trade Winds) consistently moved fastest across the entire Pacific under the persistent northeast and easterly trade winds. They then dispersed much like the Area 10 drifters with 2 out of 24 traveling to the north into the Subarctic Region.

Next we switched from the Lagrangian (following the drifters) to the Eulerian (changes at a fixed place) perspective for analysis of the number of drifters accumulating over time in each area. Figure 3 shows the locations of the all of the 113 drifters after 3, 6, and 12 years following releases in 1977.

Figure 3(a)

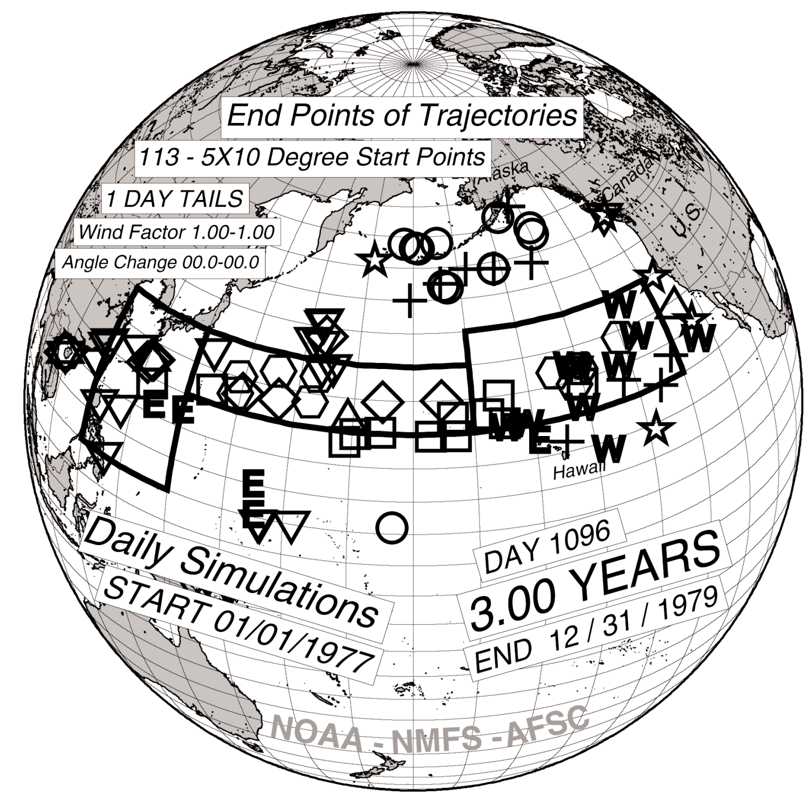


Figure 3(a). Locations of 113 OSCURS drifters 3 years (1096 days) after release (for initial distribution see figure 1). The symbols and letters correspond to the 10 areas in which drifters were released. Heavy lines outline accumulation Areas 7, 8, and 9.

Figure 3(b)

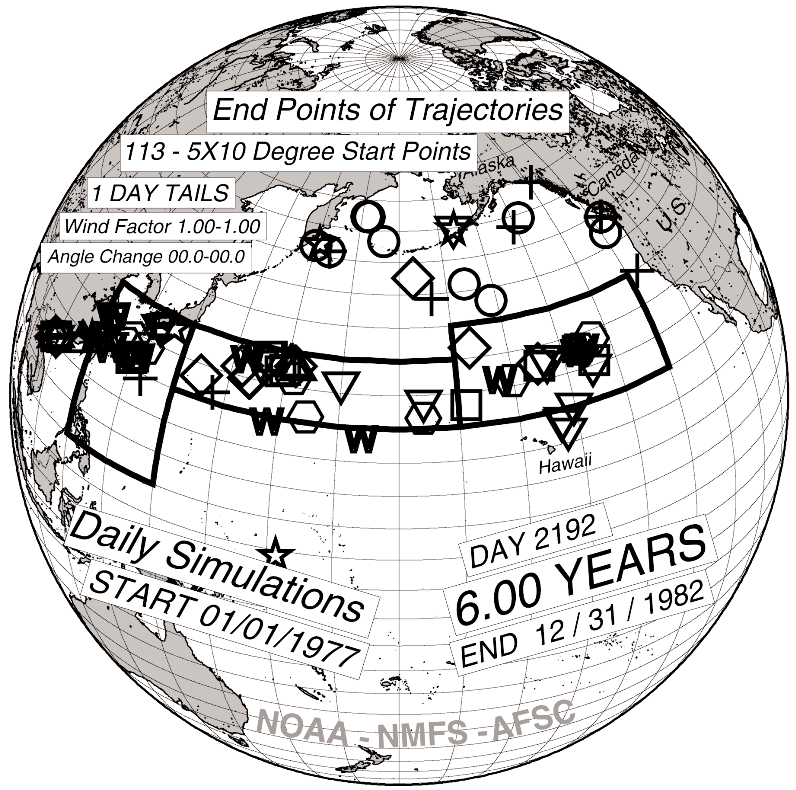


Figure 3(b). Locations of 113 OSCURS drifters 6 years (2192 days) after release (for initial distribution see figure 1). The symbols and letters correspond to the 10 areas in which drifters were released. Heavy lines outline accumulation Areas 7, 8, and 9.

Figure 3(c)

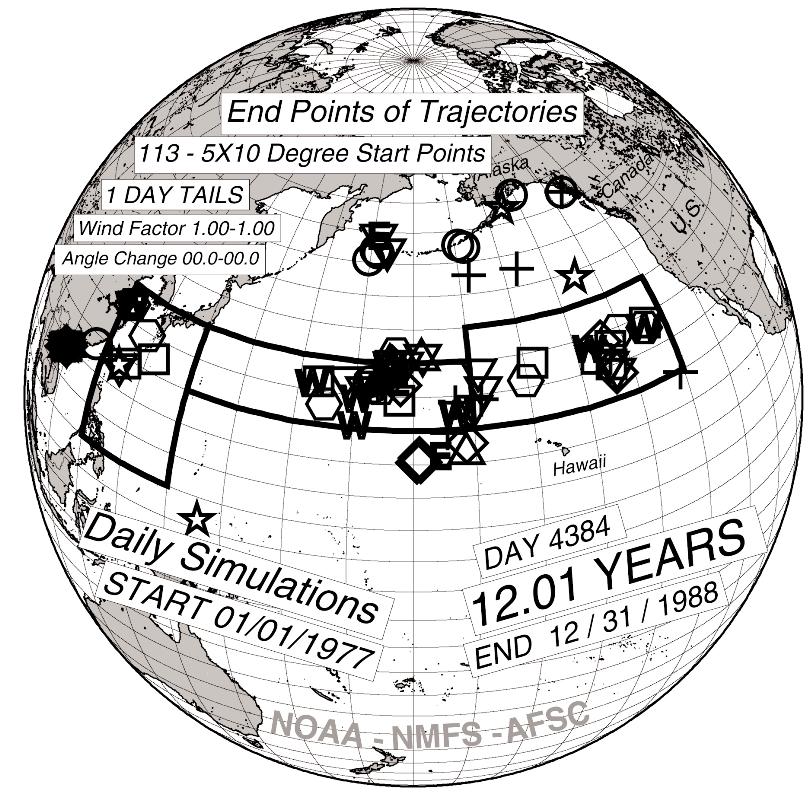


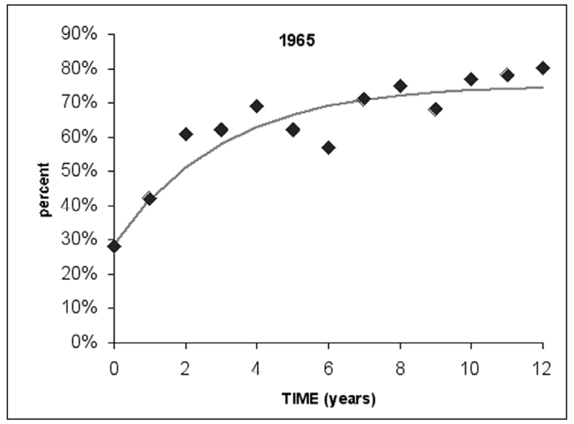
Figure 3(c). Locations of 113 OSCURS drifters 12 years (4384 days) after release (for initial distribution see figure 1). The symbols and letters correspond to the 10 areas in which drifters were released. Heavy lines outline accumulation Areas 7, 8, and 9.

It is clear from figure 3a–3c that within 3 years many of the drifters have migrated from the Subarctic Region to the Subtropic. This process continued with most of the changes evident by year 6 and only minor changes by year 12. This process of exponential accumulation is quantified below. Irrespective of whether they were released before or after the climate shift in 1977, the drifters tend to accumulate in Areas 6, 7, 8, and 9.

Drifter Time Scale

To quantify the accumulation, we tabulated the percentage of OSCURS drifters versus year in 4 obvious accumulation areas (Areas 6, 7, 8, and 9). Figure 4 shows the percentage of the 113 drifters in the 4 regions versus time for the 1965 and 1977 releases.

Figure 4



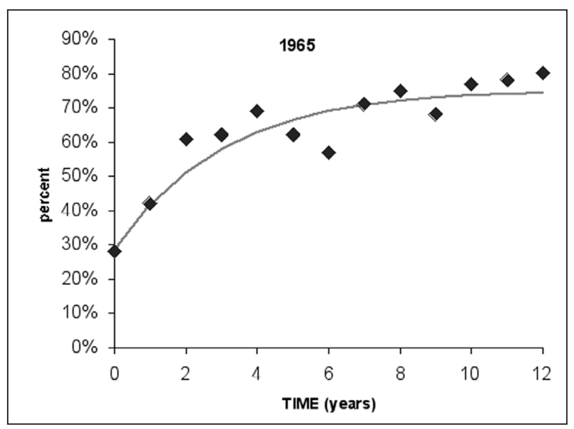


Figure 4. Percentage of 113 seeded drifters accumulating in four North Pacific Areas (6, 7, 8, and 9; see figure 1) versus year after release in 1965 and 1977. Smooth lines represent exponential model fits. Note that after 12 years, a total of 74% of all drifters are found in these four areas, whereas at the beginning of the experiment, only 28% started there.

The well-behaved nature of accumulation versus time suggests an exponential behavior. Statistical fits to the 1965 and 1977 releases provided parameters to the equation P = Pe – Piexp[-t/T], where Pe is the equilibrium percentage accumulation, Pi is the increase in percentage accumulation between the initial release and equilibrium, T is the gathering time-constant for drifter accumulation, and time (t) is expressed in years

1965-1976: P = 75% – 47%exp[-t/3.0] (1)

1977-1988: P = 71% – 45%exp[-t/2.6] (2)

On average, these four areas accumulate 43%–47% of the drifters above the initial 28% initially found there. In other words, after 12 years these 4 areas accumulate 71%–75% of the total drifters initially spread uniformly over the North Pacific Ocean. The remaining 20%–28% spread over all other areas.

The time-constant (2.6–3.0 years) indicates the time at which approximately 56%–62% of the 113 initial drifters are found within the four regions. After two time-constants (5.2–6.0 years), approximately 66%–74% of the drifters are found within the regions. At equilibrium percentages (71%, 75%), the number of drifters entering and leaving the accumulation regions are about equal.

In terms of areal coverage, the OSCURS experiment begins with 113 rectangles with one drifter released at the center of each rectangle. Areas 6–9 contain 28% of the rectangles, but end up accumulating 71%–75% of the drifters. In other words, currents and winds gathered about three-quarters of the drifters into 28% of the area.

1965 vs. 1977

Equations 1 and 2 provide a quantitative basis to compare the drifter releases before and after the 1977 regime shift.

The equilibrium percentages (Pe: 71%, 75%) differ by approximately 4%, and the percentage increases (Pi: 43%, 47%) differ by 4%. The time-constants differ by 15%. This agreement suggests secondary variations in accumulation before and after the 1977 regime shift.

Model vs. Observed Accumulation

To evaluate the field data, we compared the OSCURS results with those from the marine debris surveys by Matsumura and Nasu (1997). To do this, we summed the debris data (figure 5) that was within the OSCURS grid, then subtotaled the amount within Areas 6–9. Assuming the debris surveys represent the equilibrium condition, we compared debris with the OSCURS result, after 8 years.

Figure 5

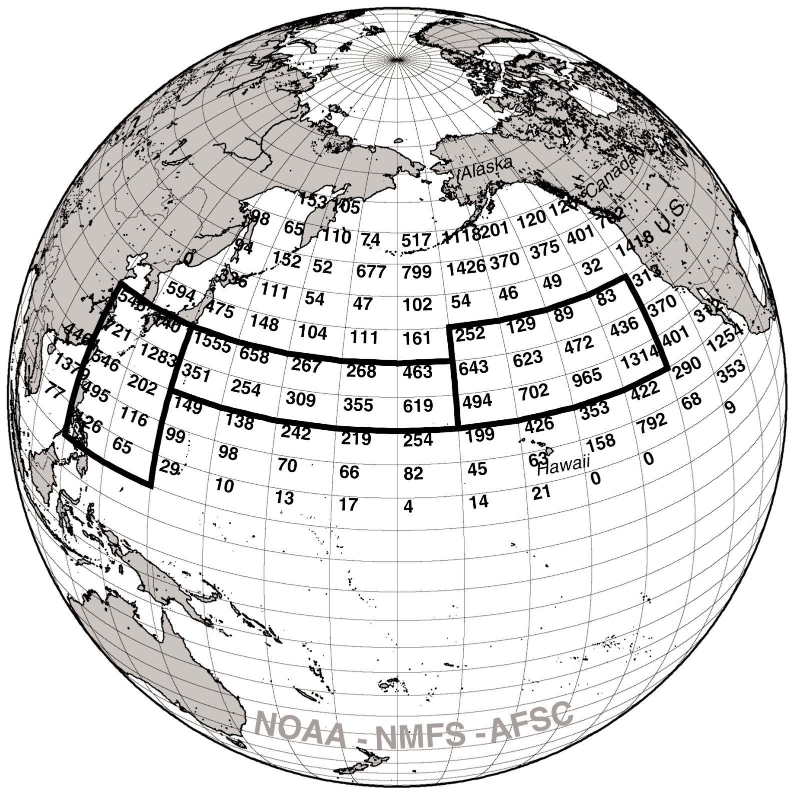


Figure 5. Accumulation Areas 6–9 (dark lines outline Areas 7–9; Area 6 is to the west) and the number of sightings of total marine debris per square nautical mile in 5° latitude by 10° longitude squares reported by Matsumura and Nasu (1997).

The four OSCURS areas (6–9) account for 52% of all marine debris reported by Matsumura and Nasu (1997) and 74% of the OSCURS drifters accumulate there. How do we compare a continuous release with the OSCURS instantaneous release? The marine debris result of 52% is about that obtained after 2 years accumulation of OSCURS drifters.

Table 1. Comparison of OSCURS drifters and marine debris surveys. OSCURS results equal the average of years 8–12 for the 1965 and 1977 releases.

Areas of North Pacific Ocean	Marine Debris Surveys	OSCURS Drifters
Total in Areas 6–9	52%	73%
Total in other Areas (1–5; 10–12)	48%	27%

DISCUSSION AND CONCLUSION

If we eliminated the sources of marine debris in this North Pacific Ocean area, the OSCURS model results show the time scale on which flotsam would accumulate. After about 6 years some 86% of it would have accumulated in the mid-latitudes with only 13% in the remainder of the North Pacific. Of course, while this accumulation proceeds, the debris degrades through processes not included in OSCURS. So, as the accumulation occurs, debris is disappearing through physical and chemical degradation.

In our experiment, we asked how surface currents and winds would redistribute an instantaneous uniform coating of marine debris distributed over the North Pacific Ocean. The time-constant, 2.6–3.0 years, is a fundamental parameter for debris accumulation in the North Pacific. This is about the time for currents to transport drifters one way across the North Pacific since both the subpolar and subtropical gyres have periods about double this value.

By analogy, we think of our experiment as observing particles in a pot of water on the stove. Before the heat is applied, the particles lie quietly, sprinkled over the water. As the water heats, convection cells begin to aggregate the particles between the cells. The time-constant is when the particles are noticeably aggregated; after two time-constants the accumulation is nearly complete. For the North Pacific, two time-constants about equal the rotational period of the two gyres.

Why do Areas 6–9 accumulate drifters? Areas 8 and 9 lie in the subtropical band in which Ekman wind effects consistently drive drifters from the north and south. Region 6 effectively traps particles because the Trade Winds drive them there, but once there, they cannot escape through the island archipelagos.

Could our results be due simply to randomness? We think not, primarily for this reason. Results for 2 time frames (before and after the North Pacific regime shift) were essentially the same.

Why do our results differ from the marine debris surveys? The comparison is not straightforward because we simulated an instantaneous release whereas the surveys reflect a continuous supply. Furthermore, in our experiment the particles do not degrade over time where presumably some marine debris disintegrated to the point of non-detection.

Many other experiments can be envisioned: OSCURS runs for continuous flotsam releases along the coastlines; releases along container vessel tracks; releases where fishing nets get loose. Would our results change for drifters having substantial windage? See figure 6 for examples of selected container spill flotsam (Ebbesmeyer and Ingraham, 1992 and 1994). These, and many additional questions we hope to answer in the near future.

Figure 6

Figure 6. Selected container spill flotsam: Nike sneaker (part of 1990 spill) found on the windward side of Oahu Island, HI in 1993; Toys (plastic beaver, turtle, frog, and duck) like many recoveries at Sitka, AK in autumn 1992; professional hockey glove found on Vancouver Island, Canada in January 1996; and "Tommy Pickles" doll head found off the Washington coast in the summer of 2000.

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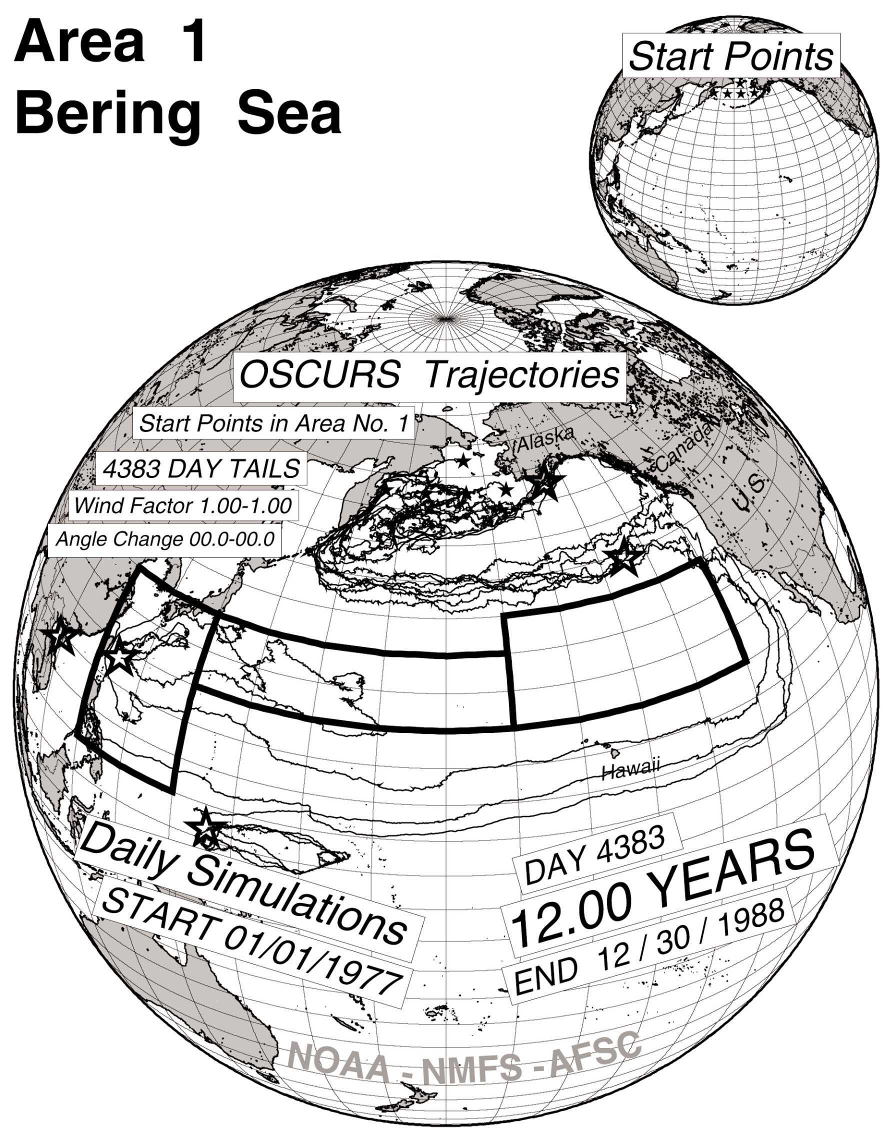
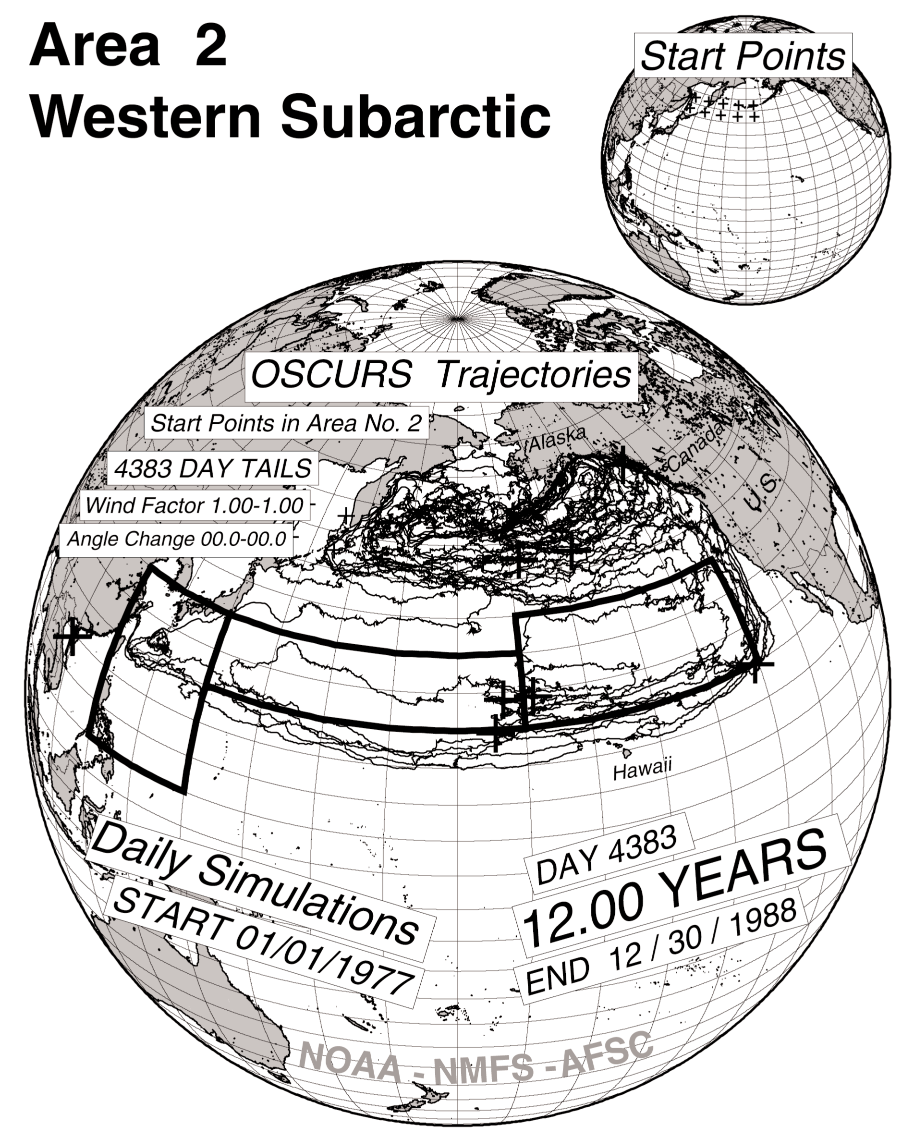
Appendix Figure 1



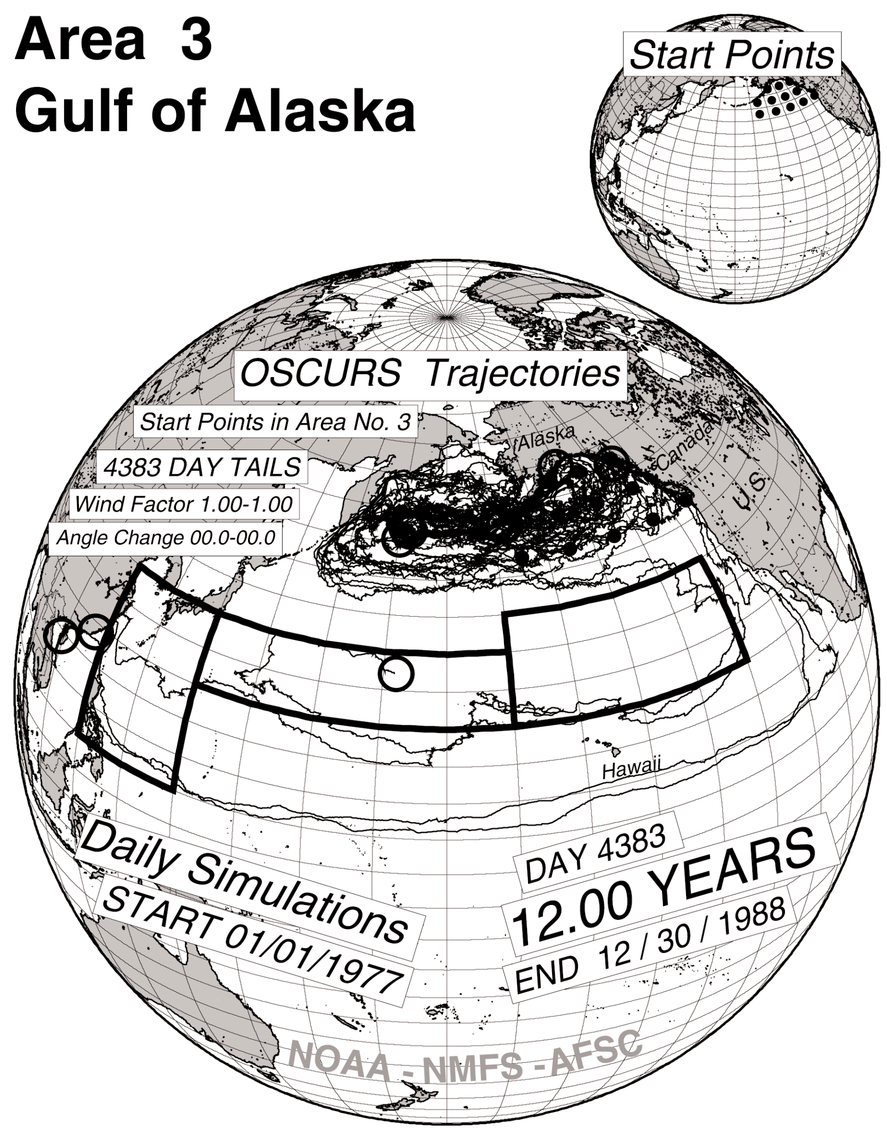
Appendix Figure 1. Start points (small solid stars) and subsequent 12-year drift trajectories for 5 drifters each started in the center of a 5° by 10° square from Area 1, Bering Sea. End points are larger open stars.

Appendix Figure 2



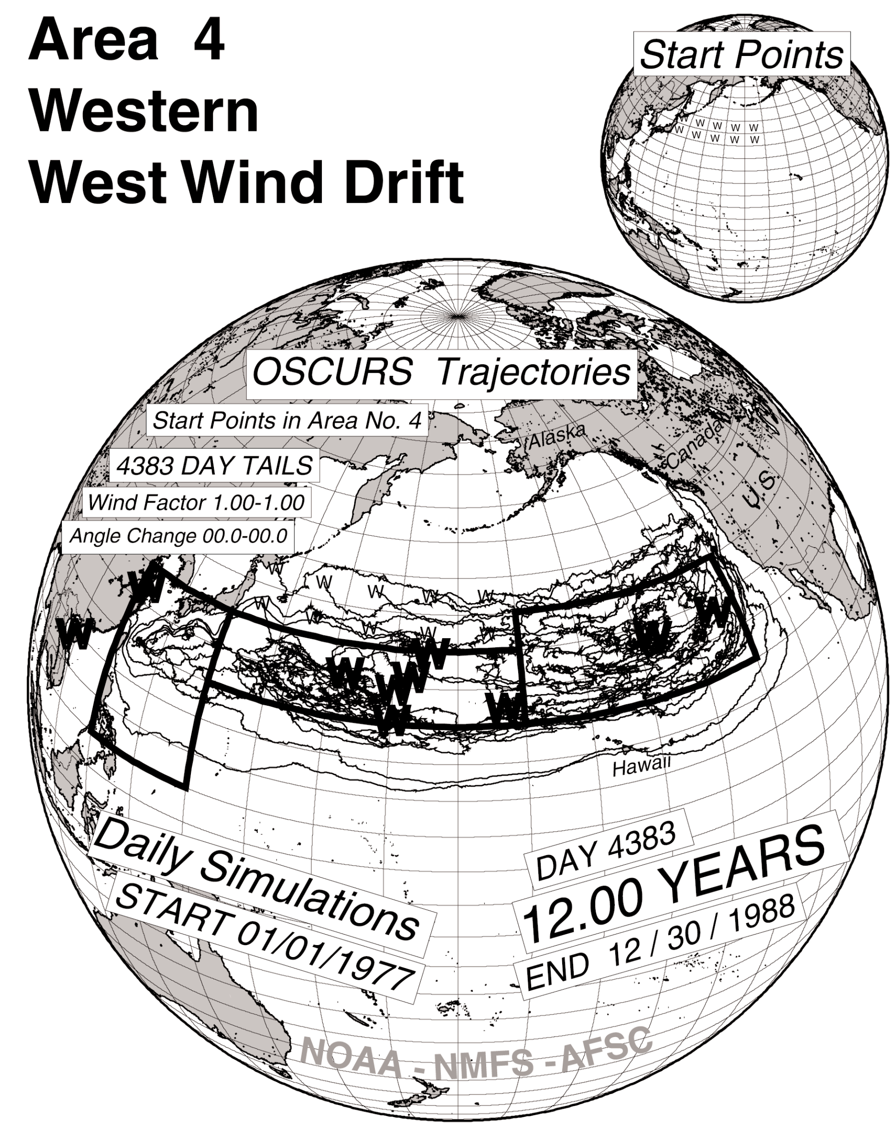
Appendix Figure 2. Start points (+) and subsequent 12-year drift trajectories for 10 drifters each started in the center of a 5° by 10° square from Area 2, Western Subarctic. End points larger bold plus signs.

Appendix Figure 3



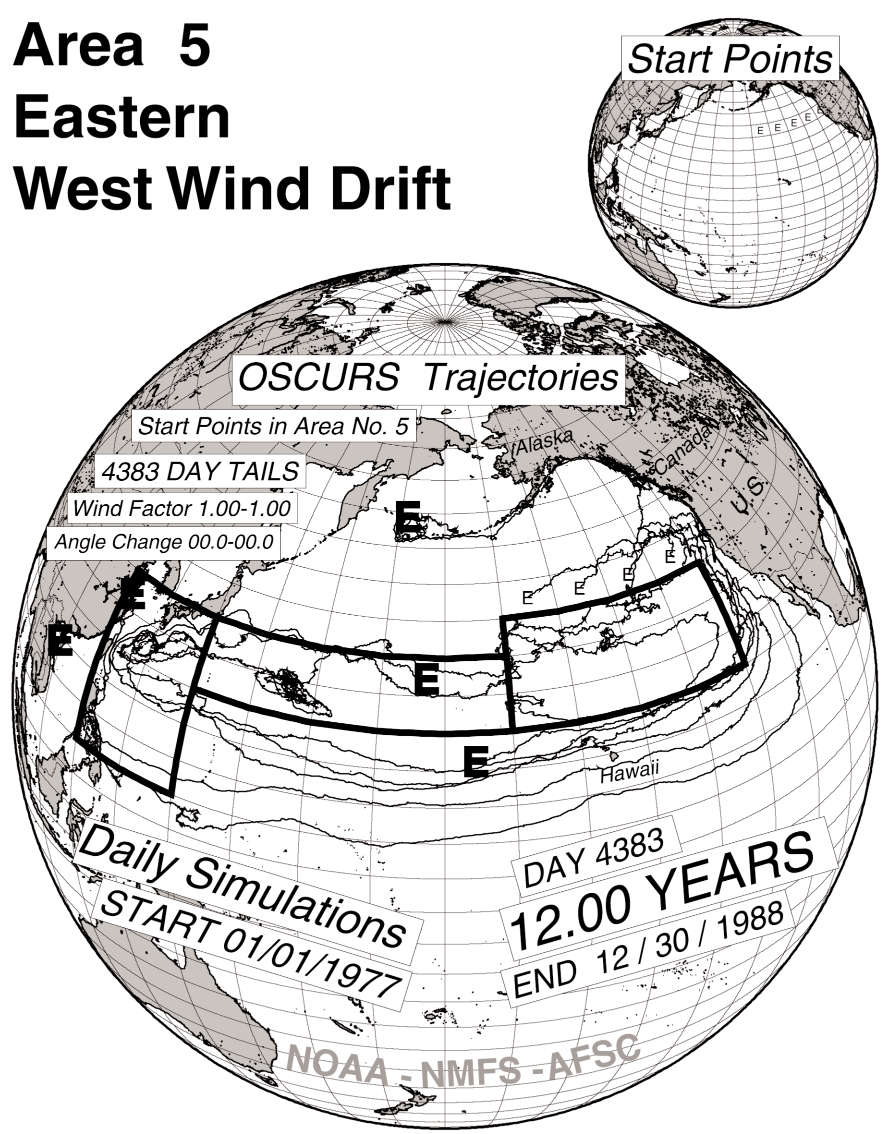
Appendix Figure 3. Start points (solid circles) and subsequent 12-year drift trajectories for 12 drifters each started in the center of a 5° by 10° square from Area 3, Gulf of Alaska. End points are larger open circles.

Appendix Figure 4



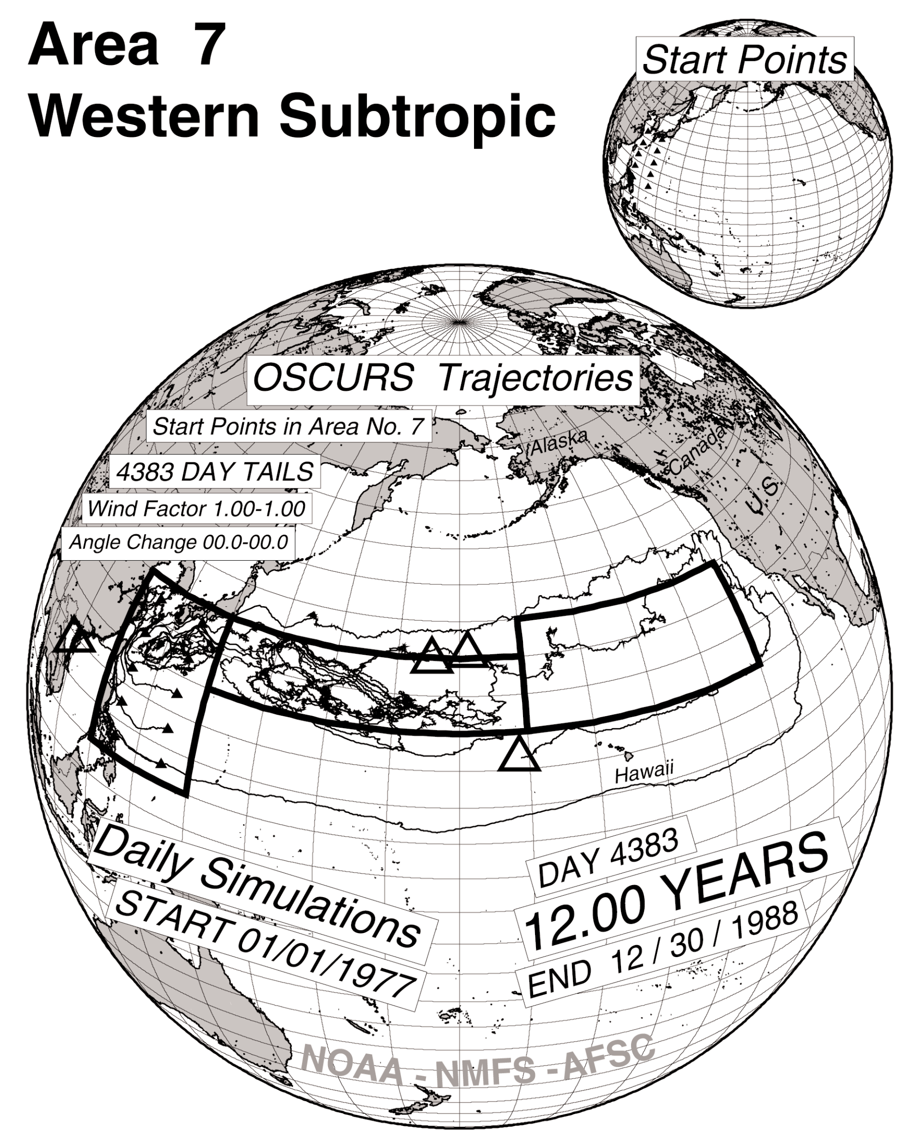
Appendix Figure 4. Start points (W) and subsequent 12-year drift trajectories for 10 drifters each started in the center of a 5° by 10° square from Area 4, Western West Wind Drift. End points are larger bold Ws.

Appendix Figure 5



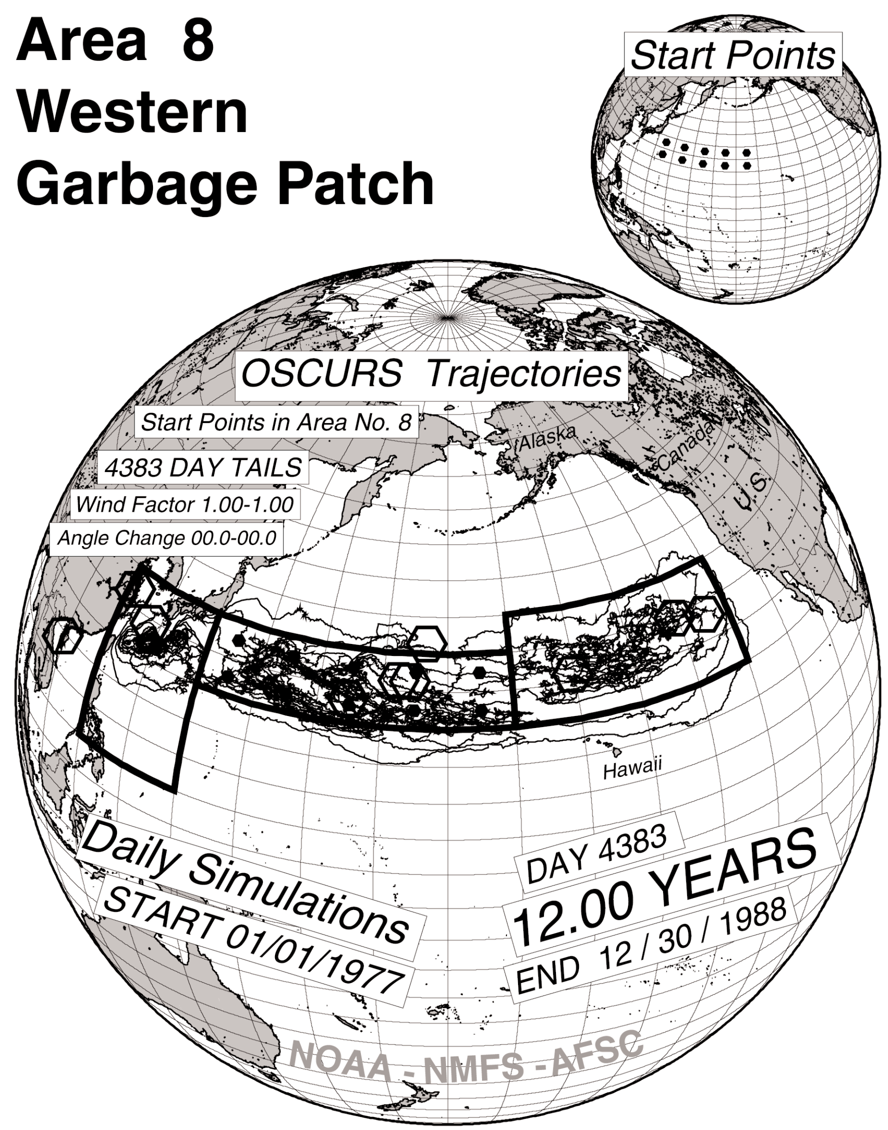
Appendix Figure 5. Start points (small E) and subsequent 12-year drift trajectories for 5 drifters each started in the center of a 5° by 10° square from Area 5, Eastern West Wind Drift. End points are larger bold Es.

Appendix Figure 6



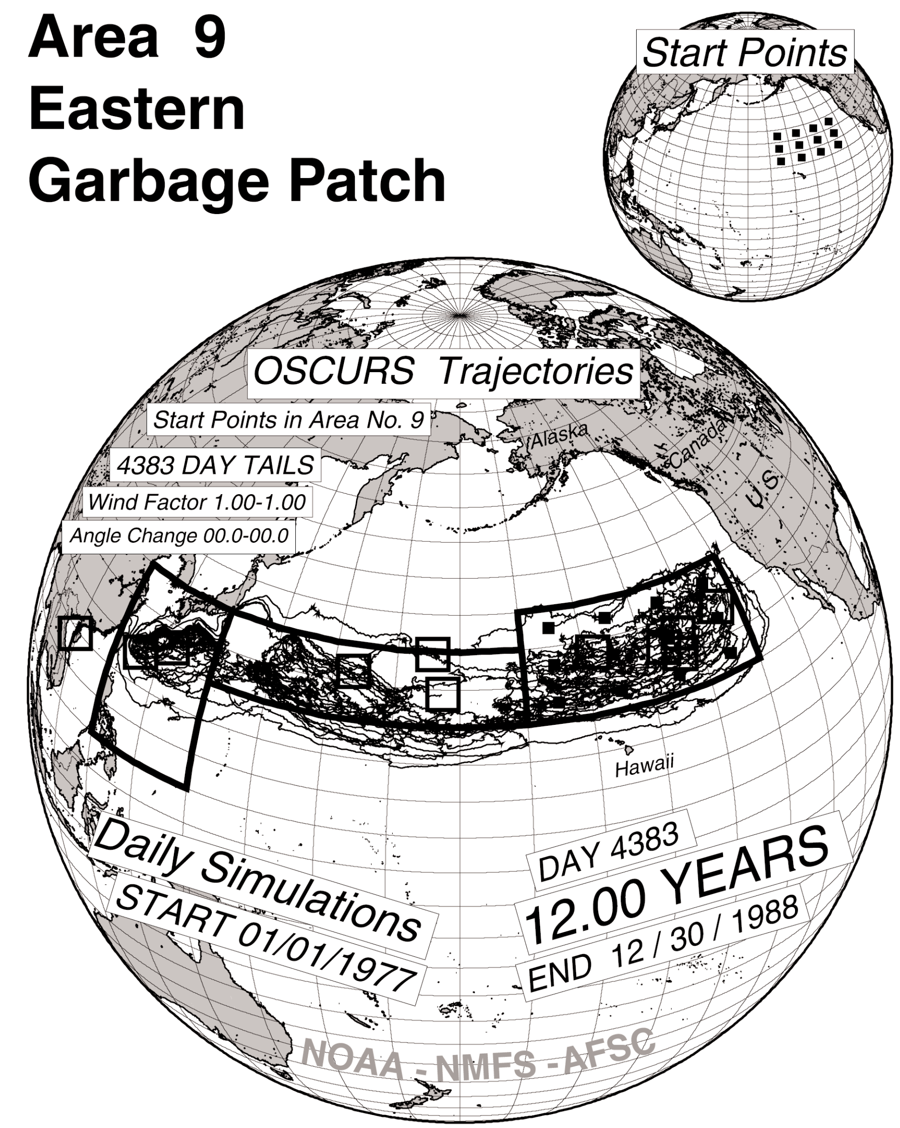
Appendix Figure 6. Start points (solid triangles) and subsequent 12-year drift trajectories for 10 drifters each started in the center of a 5° by 10° square from Area 7, Western Subtropic. End points are larger open triangles.

Appendix Figure 7



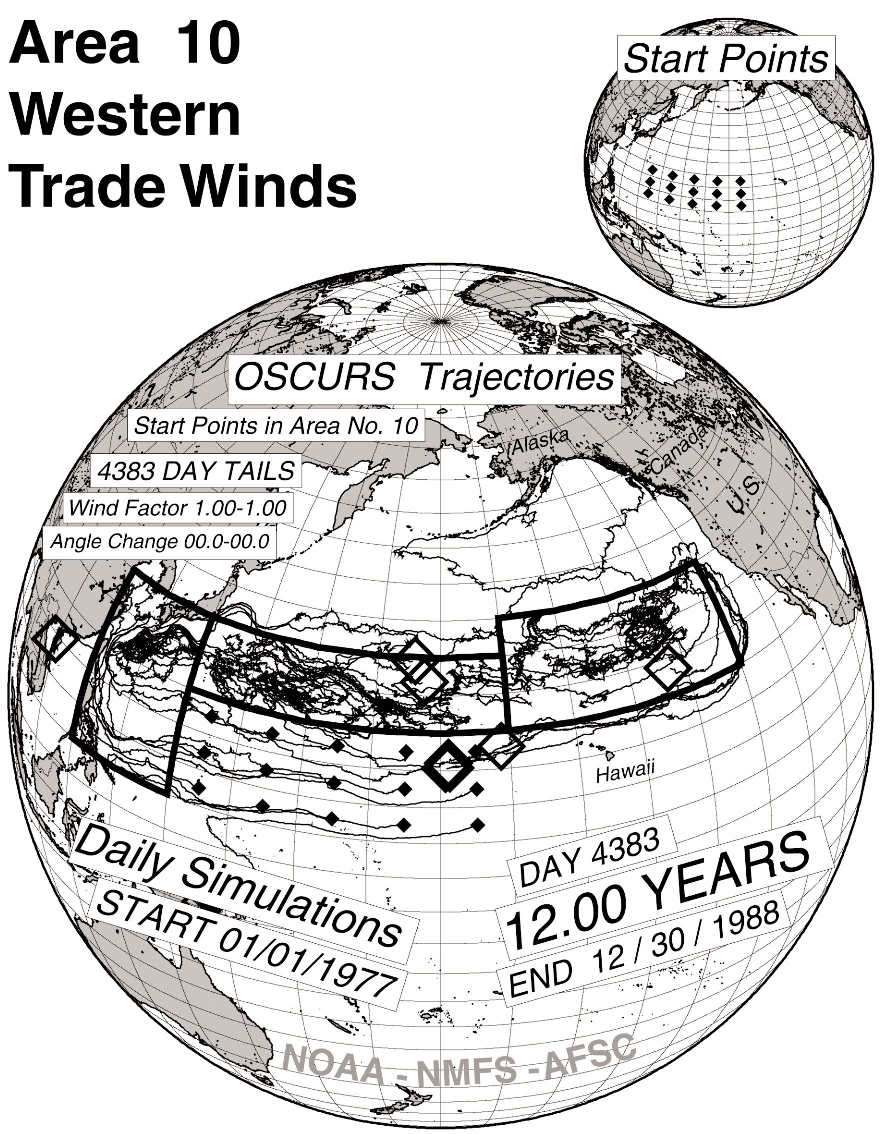
Appendix Figure 7. Start points (small solid hexagons) and subsequent 12-year drift trajectories for 10 drifters each started in the center of a 5° by 10° square from Area 8, Western Garbage Patch. End points are larger open hexagons.

Appendix Figure 8



Appendix Figure 8. Start points (small solid squares) and subsequent 12-year drift trajectories for 12 drifters each started in the center of a 5° by 10° square from Area 9, Eastern Garbage Patch. End points are larger open squares.

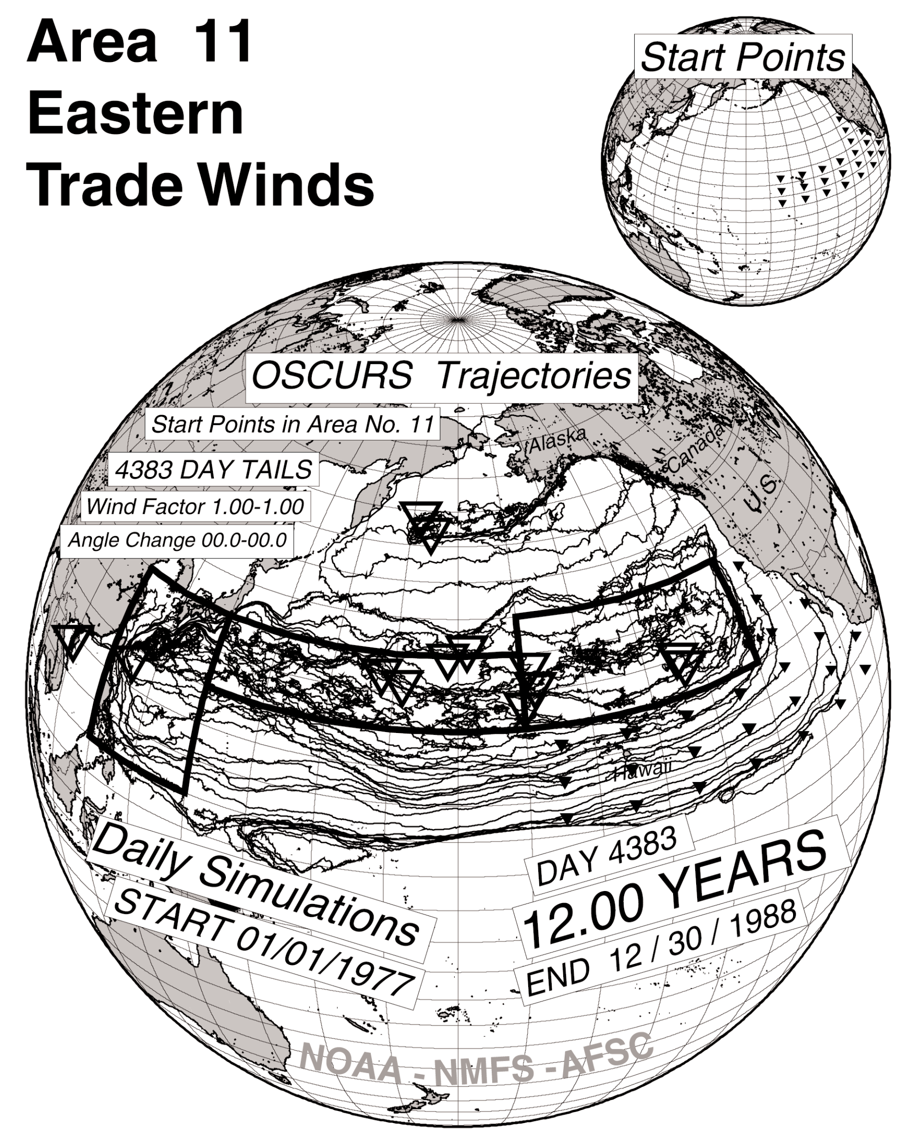
Appendix Figure 9



Appendix Figure 9. Start points (u) and subsequent 12-year drift trajectories for 15 drifters each started in the center of a 5° by 10° square from Area 10, Western Trade Winds. End points are u.

SURFACE CURRENT CONCENTRATION OF FLOATING MARINE DEBRIS IN THE NORTH PACIFIC OCEAN:
12-YEAR OSCURS MODEL EXPERIMENTS

Appendix Figure 10



Appendix Figure 10. Start points (t) and subsequent 12-year drift trajectories for 24 drifters each started in the center of a 5° by 10° square from Area 11, Eastern Trade Winds. End points are larger open inverted triangles.

MARINE DEBRIS MONITORING AND DATA COLLECTION ACTIVITIES

CONDUCTED BY THE CENTER FOR MARINE CONSERVATION

Charles G. Barr, Program Manager, Center for Marine Conservation, Virginia

INTRODUCTION

Human-generated trash and debris has been a recognized marine pollution issue since the late-1960s and early-1970s (Ribic, et al., 1992; Coe, 1997). Over the past two decades, scientists, conservationists, policy makers and the general public have realized a need to understand the nature of the debris in order to examine ways to reduce and eliminate the problem. Marine debris has been identified as coming from two general sources: land-based debris and ocean/maritime based sources. It is a common belief by many that the primary source of marine debris is from ocean-based sources, when in reality, studies show that 60%–80% of the debris accumulating on our shorelines is land-generated (CMC, 1998). Though ocean-based debris has historically accounted for less than 15% of the total number of items found during the Center for Marine Conservation's International Coastal Cleanups (CMC ten-year data analysis), the nature of the debris is of great concern. Ocean-based debris in the form of abandoned nets, ropes, and monofilament fishing line made of strong, durable, synthetic materials poses a severe threat to wildlife, degrades habitats, and threatens human health and safety.

The Center for Marine Conservation (CMC) has long recognized the threat to the environment posed by marine debris pollution, and has been involved in the monitoring of marine debris for over fourteen years. CMC's International Coastal Cleanup (ICC) program is the world's largest volunteer effort designed to remove debris from the shorelines, waterways, and beaches of the world, and at the same time, collect and catalogue important information on the nature and quantity of the debris. CMC is also engaged in a comprehensive five-year scientific study on marine debris called the National Marine Debris Monitoring Program (NMDMP), funded by the U.S. Environmental Protection Agency (EPA). The NMDMP is a statistically valid marine debris survey designed to detect trends in marine debris occurring on the coastal shores of the U.S. It is the goal of both programs to shed more light on the nature of marine debris and develop means to address the sources and activities that contribute to marine debris pollution.

HISTORY

Since mankind set sail upon the oceans hundreds of years ago, the oceans have been a dumping ground for human-generated trash and debris. Just as waste generated on land was disposed into open landfills, garbage generated at sea was simply discharged overboard (National Research Council, 1995). This debris provoked little concern as an environmental issue due to the fact that the trash was composed of materials that easily decayed or degraded.

Since the 1950s, the nature of the trash and debris began to take on a new character with the development of plastics (MMC, 1990). Over the last fifty years, society has embraced the benefits and use of plastics. Its strength, durability, light weight, versatility, ease of production and handling, and low cost were quickly utilized by industry for manufacturing and packaging, making plastic preferable over other materials (ITF, 1988).

By the early-1980s, it was becoming increasingly apparent that the changing nature of marine debris was posing a significant threat to marine life, mariners, and beach goers as well as becoming an economic burden on oceanfront communities. Plastic and synthetic materials, when disposed or lost at sea, injured and killed many forms of marine life, including marine mammals, through entanglement and ingestion. At least 267 marine species were affected by entanglement and ingestion (MMC, 1995; Farris and Hart, 1995). Marine debris also became entangled in the propellers of boats or clog water intakes of marine engine cooling systems, thus disabling boats and leaving its passengers stranded. The health and safety of beach goers was also threatened by sharp glass, metal, and plastic, along with medical waste. And beach communities, whose economic base is driven by a steady influx of tourism, lost millions of dollars due to lost tourism and increased beach cleanup maintenance (National Research Council, 1995). It was increasingly becoming recognized that marine debris had become a major pollution issue.

In order to understand the impacts and significance of any pollution problem, it is necessary to identify its composition and sources (IOC, 1991). Prior to 1986, an estimate of the types and quantities of debris effecting our coastal areas and shorelines was unknown. In September of 1986 in Texas, the Center for Marine Conservation (formally Center for Environmental Education) launched its first large-scale beach cleanup campaign and marine debris survey. The purpose was to remove debris from the environment and to document the types and quantities of debris plaguing our nation's beaches. The event proved to be such a success in collecting information on marine debris and heightening public awareness that the program has continued annually through to the present.

Prompted by the recognition of the threat posed by marine debris pollution, and armed with marine debris data collected through CMC's International Coastal Cleanups, the U.S. government ratified and enacted important marine debris legislation. In 1987, the U.S. Congress ratified Annex V of the International Convention for the Prevention of Pollution from Ships (MARPOL 73/78). This important set of legislation was aimed at addressing marine debris pollution at its source. Annex V, which became effective in 1988, prohibits the at-sea disposal of plastic waste and regulates the distance from shore that all other solid waste materials can be dumped. Also enacted in 1987 was the Marine Plastic Pollution Research and Control Act (MPPRCA, Public Law 100-220, Title II), which extends MARPOL Annex V legislation to all navigable waterways of the U.S. Though this legislation is important, enforcement has been difficult and costly.

In 1989, the National Oceanic and Atmospheric Administration (NOAA) and the National Park Service (NPS) agreed to conduct a five-year pilot study developing standardized methods for quantifying marine debris. In addition, the EPA and other Federal Agencies established a working group to monitor marine debris status and trends as directed by the MPPRCA (section 2204). The MPPRCA required that the EPA, NOAA, and the U.S. Coast Guard (USCG) form "Citizen Pollution Patrols" utilizing volunteers to monitor, cleanup, and prevent ocean and shoreline pollution.

In 1990, the EPA was instructed by Congress to assess the effectiveness of marine debris legislation and other methods to control debris. The EPA and CMC joined in the effort since the most geographically comprehensive and continuous set of marine debris data had been collected and compiled in CMC's International Coastal Cleanup Database. The International Coastal Cleanup Database has provided a means to assess and review the nature and characteristics of marine debris pollution over the past fourteen years. The marine debris information gathered during the annual International Coastal Cleanup surveys, though useful and valuable, is a non-scientific means of collecting information that, at best, provides a snapshot into the nature of marine debris. It was apparent that a standardized method of monitoring marine debris was needed to statistically determine if existing legislation was working to reduce the debris in our oceans.

In 1990, Congress appropriated funds to the EPA for the development of demonstration programs to utilize volunteers in monitoring and removing marine debris from selected beaches in New Jersey and Maryland. As part of the program, CMC, in conjunction with the EPA, began to test a statistically valid methodology designed by Ribic (1991) for determining trends in marine debris. Beach sites were selected in Maryland, New Jersey, Texas, and Alabama and volunteers were recruited and trained in the program protocol. As a result, a methodology was developed by a working group comprised of representatives from NOAA, NPS, CMC, USCG, the Marine Mammal Commission (MMC), and selected scientists and was reviewed by all federal agencies that monitored marine debris. The resulting methodology has led to the development of National Marine Debris Monitoring Program (NMDMP) currently being conducted by CMC with funding from the EPA.

INTERNATIONAL COASTAL CLEANUP

The Center for Marine Conservation's annual International Coastal Cleanup (ICC) is the world's largest volunteer effort designed to remove debris from inland and coastal shorelines and collect data on the quantity and nature of marine debris. The program is also designed to educate the public on marine debris issues and effect positive change resulting in the reduction and eventual elimination of marine debris pollution. The ICC has been held annually since 1986 and cumulatively has involved over three million volunteers in over one hundred countries bordering every major body of water on Earth.

Each year hundreds of thousands of volunteers worldwide scour the shorelines collecting debris and cataloguing information on the nature and quantity of the items. The information collected by the participants in the ICC not only provides documentation on the nature of marine debris items but also provides insights into regionally significant sources of the debris.

BACKGROUND

The Center for Marine Conservation's first beach cleanup and debris survey occurred in 1986 along the coast of Texas in response to growing concerns over the large amounts of debris appearing along the Texas shorelines. The initial event was called the Texas Coastal Cleanup, and drew approximately 2,800 volunteers. The volunteers collected nearly 7,900 trash bags with 124 tons of debris from 122 miles of coastline. The success of the initial beach cleanup event encouraged CMC to make the activity a yearly event. The beach cleanup also provided an opportunity to collect information on the nature and quantities of debris appearing on U.S. shorelines. By 1989, the beach cleanup had grown to 24 U.S. states, 2 U.S. territories, and sites in Canada and Mexico, with the participation of 65,000 volunteers. Fourteen years after its inception the ICC, in 1999, had expanded to 78 countries with the participation of over 774,000 volunteers who collected 8,439,000 pounds of debris from over 11,300 miles of shoreline.

Volunteers have collected information on the types and quantities of debris since the inception of the ICC in 1986. The purpose of data collecting and recording has been twofold: first, to document the nature of the debris, and second, to quantify and track the amount of debris being found. The result has been the development of the world's largest marine debris database; the International Coastal Cleanup Database that contains information from fourteen years of beach cleaning activities.

METHODOLOGY

The International Coastal Cleanup (ICC) is a three-hour event that takes place annually on the third Saturday of September. In the event that the ICC needs to be postponed or rescheduled, local event coordinators have until the end of October to complete the activity. Each country, U.S. state, and U.S. territory has a designated survey coordinator responsible for the organizing of volunteers for the event. CMC provides ICC materials such as data cards, trash bags, and other support materials to help make the event a success. Volunteers conduct their cleanup activities and debris surveys along their local coastal beaches and the shorelines of rivers, lakes, and streams. Since many volunteers repeatedly participate in the ICC, many of the same locations are annually cleaned and surveyed.

The ICC is a loosely structured survey designed to make a snapshot assessment of the types and amounts of debris found on cleanup day. The ICC does not employ a scientific protocol to be followed by the volunteer participants. Due to differences and inconsistencies in the method of data collection, users of the ICC information gathered during these events are cautioned in comparing data from year to year and from site to site. Variability in the cleanup sites occurs from year-to-year, and from site-to-site. For example, one location may have 1,000 volunteers cleaning ten miles of shoreline, while another location may have only five volunteers cleaning one mile of shoreline. Though the marine debris data collected during the ICC events does not lend itself to statistical analysis, it does provide important and useful information on the nature of marine debris worldwide.

The ICC data card standardizes the information to be collected by the event volunteers. On the day of the event, volunteers are provided with an ICC data card and asked to provide information on their efforts and the items that they find during the activity. Volunteers are asked to provide information on the number of people working together on the data card (usually one person is designated as a recorder in a group of people), number of trash bags filled, total distance they clean, and total estimated weight of debris collected. Over the years the number of items on the data card have varied and changed to reflect changes in societies' packaging and technologies. The original 1986 Texas Cleanup data card listed only 34 items. Today, the ICC data card lists 81 specific items commonly found as debris with space to record unlisted items. Items are grouped in eight major categories according to their compositional make-up (i.e., plastic, foamed plastic, glass, rubber, metal, paper, wood, cloth). Volunteers are instructed to use tally marks or "tick-marks" as they count the various items and then total their quantities based on their counts. Information is also recorded on the data card regarding entangled animals (specifying the form of entanglement) and items with foreign labels. Volunteers are also asked to record any peculiar items. Space is provided for volunteer comments/observations during the cleanup.

Upon completion of the beach clean up activity, data cards are returned by mail to CMC for processing. Each year, thousands of data cards are then received from all over the world. In 1999, approximately 25,000 cards were returned from volunteers. Each data card that is received is carefully reviewed before its information is entered into the CMC database. Any questionable amounts of debris are screened and checked. This requires the manual recounting of all the count tick marks to verify the totals being reported by the volunteers. The card review process is very labor intensive and may even require contact-

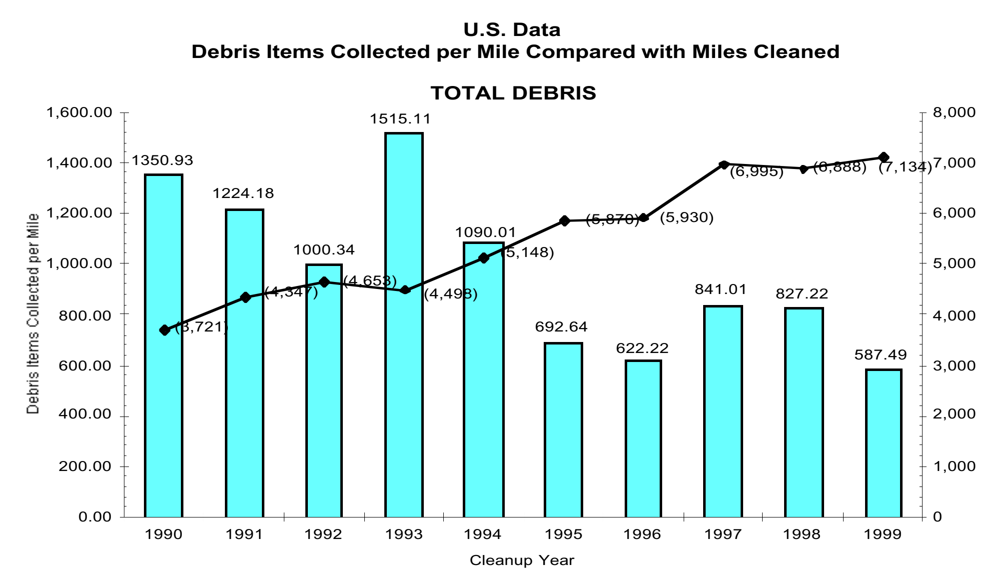
ing local site coordinators or the individual volunteer who recorded the initial information to verify the findings. If recorded totals are written in by volunteers without verifying the count tick marks appearing on the card, an underestimate is substituted for quantity of that item. Once the cards are thoroughly checked and interpreted for accuracy, the information is then manually entered into the database.

FINDINGS

With over ten years of collecting information on marine debris through the ICC, what is the data telling us? As stated earlier, caution must be used in how we interpret the ICC data. The data offers us, at best, a snapshot of the types and quantities of marine debris being found on our beaches and the shores of our waterways. By examining the data collected from year to year, we can recognize patterns in marine debris at the local, regional, national, and global levels. The analysis and interpretation of the ICC data can be used to effect positive change in our societies' waste handling practices as well as encourage policies and laws that can better address solid waste management.

An overview of the past ten years of ICC data collected in the U.S. shows how the event has grown over the years and that the data suggest that progress is being made in reducing marine debris. In an examination of U.S. ICC data from 1990 to 1999, we see a substantial decline in the amount of debris being found and collected by volunteers. In 1993, volunteers cleaned and surveyed 4,498 miles of shoreline resulting in 1515.11 debris items collected per mile. By 1999, volunteers had cleaned over 7,000 miles of shoreline and were reporting only 587.49 debris items per mile (figure 1).

Figure 1



PERCENT COMPOSITION OF MARINE DEBRIS

The ICC data card separates the list of debris items by material composition (i.e., plastic, foamed plastic, glass, rubber, metal, paper, wood, cloth). After examining over ten years of ICC information, 1988–1998, it was not surprising to find that plastic consistently constituted the greatest percentage of all debris found in the U.S. Plastic items composed an average of approximately 60% (low of 53.19%; high of 64.54%) of all items found during the annual ICC beach cleanups and surveys. In 1997, five regions reported plastic percentages above the worldwide average: Black Sea (82.53%), Indian Ocean (69.99%), North Sea (65.79%), Wider Caribbean (64.27%), and the Pacific Ocean (62.95%). Central Europe was reporting the lowest percentage with 42.79% (CMC, 1997).

It is interesting to note that the calculations for percent composition of plastics do not include the numbers of cigarette filters found during the ICC surveys. Cigarette filters are considered a plastic item, however, their great abundance would skew the percent composition information if their numbers were to be included.

Paper, metal, and glass constituted nearly equal percentages based on composition from 1988–1998. Paper constituted an average of 11.43% of all items. Metal constituted an average of 10.28% of all items. Glass constituted an average of 10.72% of all items.

Wood, rubber, and cloth constituted the lowest percentages based on composition and were closely grouped from year to year, 1988–1998. Wood constituted an average of 2.80% of all items, while rubber constituted an average of 2.23% of all items, and cloth constituted an average of 1.32% of all items.

THE DIRTY DOZEN

Each year a list is compiled of the twelve most abundant debris items collected along the world's shorelines, waterways, and underwater. The list known as the "Dirty Dozen" has shown relatively little change over the past ten years.

1999 ICC Dirty Dozen-International

	Items	% of total debris collected
1.	cigarette filters	13.27%
2.	food bags/wrappers (plastic)	8.11%
3.	plastic pieces	6.17%
4.	foamed plastic pieces	5.05%
5.	paper pieces	4.21%
6.	glass pieces	4.08%
7.	caps/lids (plastic)	3.60%
8.	other plastic items	3.12%
9.	beverage bottles (plastic)	2.71%
10.	beverage bottles (glass)	2.70%
11.	straws	2.65%
12.	beverage cans	2.48%

Cigarette filters are consistently the most abundant debris item collected each year. Though wrapped in paper, the filter fibers are made of cellulose acetate, a synthetic polymer, and are therefore classified as a plastic. Cigarette filters are not just an aesthetic problem. They have been found in the stomachs of juvenile birds, sea turtles, and other marine life.

SOURCES OF DEBRIS

The sources of marine debris can generally be divided into land sources, ocean/waterway sources, and general sources. Debris items originating from land-based sources are the result of activities related to littering, beach users, surf fishing, picnics, landfills, manufacturing plants, sewage treatment plants, storm drains, and combined sewage overflows (CSOs). Ocean/Waterway-based sources of debris are the result of activities related to littering (from piers/docks/boats), recreational boating, recreational fishing (from piers/docks/boats), commercial fishing, merchant vessels, military/research vessels, and offshore oil/gas platforms. Many items that are found during the annual debris surveys come from sources we consider general source items. Items are designated as general source due to the potential of multiple usages being responsible for generating these items. Items classified as general source items cannot be traced to a specific activity or sole source.

DEBRIS SOURCE INDICATOR ITEMS

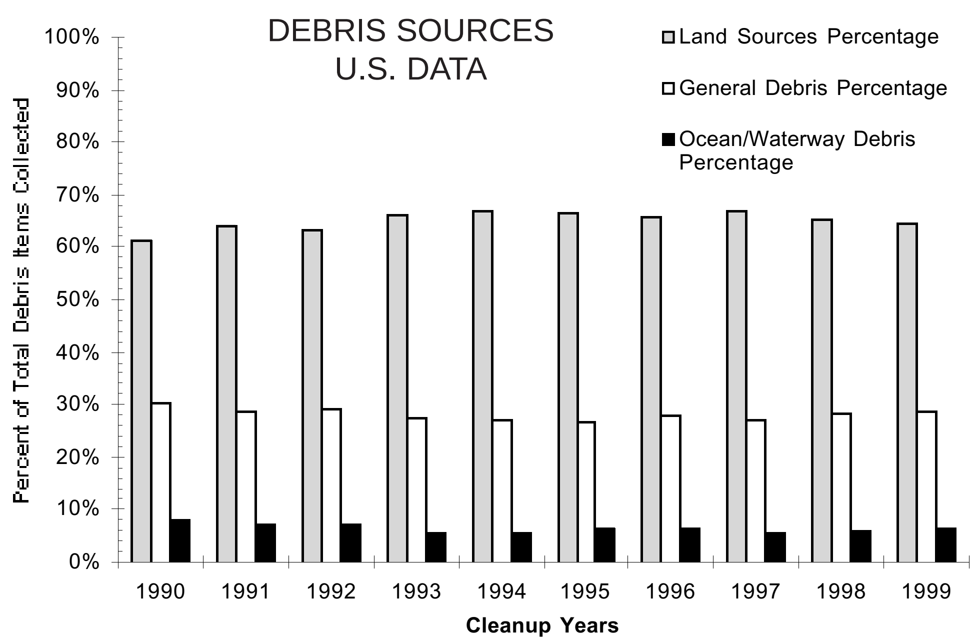
Land-based Sources include food bags/wrappers (plastic), beverage bottles (plastic), caps/lids (plastic), cigarette butts, cigarette lighters, cups, utensils (plastic), diapers, six-pack holders, straws, syringes, tampon applicators, toys, cups (foamed plastic), fast food containers, plates (foamed plastic), beverage bottles (glass), balloons, condoms, bottle caps (metal), aerosol cans, beverage cans, pull tabs, wire, paper bags, cups (paper), newspapers/magazines, plates (paper), lumber pieces, and clothing/pieces.

Ocean/Waterway-based Sources include salt bags (plastic), trash bags (plastic), bleach, cleaner bottles, milk/water gallon jugs, oil, lube bottles, buckets, fishing line, fishing lures, floats, fishing nets, hard hats, light sticks, pipe thread protector, rope, sheeting longer than two feet (plastic), strapping bands (plastic), vegetable sacks, "write protection" rings, buoys, egg cartons (foamed plastic), meat trays, fluorescent light tubes, light bulbs, gloves (rubber), food cans, crab/lobster traps (metal), crab/lobster traps (wood), crates, and pallets.

General Sources include other plastic bags, other plastic bottles, plastic pieces, sheeting two feet or shorter (plastic), other plastic items, packaging material (foamed plastic), foamed plastic pieces, other foamed plastic items, food jars (glass), other bottles/jars (glass), glass pieces, other glass items, tires, other rubber items, other cans, 55-gallon drum s (rusty), 55-gallon drums (new), metal pieces, other metal items, cardboard, cartons, paper pieces, other paper items, and other wood.

When we examine a break down of the U.S. data (1990–1999) by percent of total debris items collected with regard to sources per year, we see great consistency from year to year (figure 2). Land-based sources of debris have ranged from 60%–70% each year, while general-sourced items have ranged from 25%–30% each year, and ocean/waterway-based sources of debris have ranged from 4%–8% each year.

Figure 2



If we examine the data collected regionally by U.S. states, we can identify areas that are exhibiting higher than average amounts of debris by source. For example, in New York and New Jersey from 1989 to 1995, the U.S. ICC data consistently indicated greater amounts of Land-based debris in the form of sewage and medical waste. In 1999, U.S. ICC data indicated higher than average Ocean/Waterway sourced debris related to commercial and recreational fishing being reported in Alaska (12.3%), Washington (16.9%), Texas (15.1%), and Hawai'i (8.6%).

Though the great majority of the debris collected and recorded during the ICC emanates from Land-based sources, the Ocean/Waterway-based sources of debris constitute some of the greatest risks to wildlife. Each year during the ICC, volunteers are asked to report discoveries of any entangled wildlife and the form of entanglement. Reports of entangled, dead animals have included invertebrates, fish, amphibians, birds, reptiles and mammals. Over the past five years (1995–1999), a total of 841 animals have been reported dead and entangled in debris during the ICC. Monofilament fishing line accounted for 385 dead and

entangled animals. Discarded monofilament fishing line has consistently been the leading cause of recorded animal entanglement deaths since the beginning of the ICC data collection. In addition to monofilament fishing line, the following debris items are responsible for the most numerous animal associated deaths due to entanglement over the past five years: fishing nets (138); nylon rope (105); plastic bags (95); string/ribbon (64); and fish/crab traps (54). The durability and strength of monofilament fishing line, nets, and rope present the greatest threat to wildlife and require an increased effort to prevent these materials from being discarded at sea.

ADDRESSING THE PROBLEM OF MARINE DEBRIS

It is evident from information collected annually through CMC's International Coastal Cleanup that marine debris remains a worldwide pollution issue. With inspiration from CMC's International Coastal Cleanup, environmental groups around the world have begun taking action to reduce and prevent marine debris in their home waters.

Here in the U.S., CMC has developed and implemented a variety of programs designed to address marine debris at its various sources:

- CMC's Model Communities Program is designed to help communities develop workable solutions to specific marine debris issues. Successful approaches can then be replicated in communities around the country.
- CMC's Million Points of Blight storm drain stenciling program is designed to heighten public awareness of the problem of non-point source pollution. Communities stencil local storm drains with the message "Don't Dump—Drains to Waterway."
- CMC's Good Mate Recreational Boating and Marina Program is an education and training program for marina staff and recreational boaters designed to increase awareness of the potential impacts of everyday boating activities. Five key pollution issues are addressed: (1) marine debris, (2) fuel and oil, (3) sewage, (4) boat maintenance, and (5) storm water runoff.

The information and data collected from the ICC has proved to be an important tool in cataloguing and documenting the nature of marine debris worldwide. The ICC has also served as a valuable mechanism to heighten public awareness of the problem of marine debris pollution, while at the same time, empowered local citizens to take direct action in helping to solve the problem. Marine debris, however, continues to be a major form of pollution. Continued monitoring and research is required in order to effectively reduce and eliminate the environmental threats posed by marine debris.

SCIENTIFIC DATA: NATIONAL MARINE DEBRIS MONITORING PROGRAM

The National Marine Debris Monitoring Program, coordinated by CMC and funded by the EPA, is a scientifically valid marine debris study examining the occurrence of thirty specific marine debris items occurring on U.S. coastlines. The program is designed to answer two specific questions: Is the amount of debris on our coastlines decreasing? What are the major sources of the debris? Trained NMDMP volunteers monitor selected beaches for marine debris and conduct beach cleanups every 28 days over a five-year period. The NMDMP takes the idea of beach cleanups a step further by standardizing marine debris collection using a scientifically valid protocol to determine the status and trends of marine debris pollution.

BACKGROUND

The establishment of the NMDMP monitoring sites was started in the spring of 1996 after a five-year pilot program designed by a working group composed of representatives from CMC, EPA, NOAA, the NPS, and selected researchers. The workgroup concluded based on the results obtained during the pilot program. The goal of the NMDMP is to be able to measure a 30% change in 30 selected marine debris items on U.S. coastal shorelines, with a Type I error rate of 0.10 and power of 0.84. This will require the monthly sampling of 20 beach sites per 9 coastal regions, for a 5-year period (Ribic, 1991; Ribic et al., 1992).

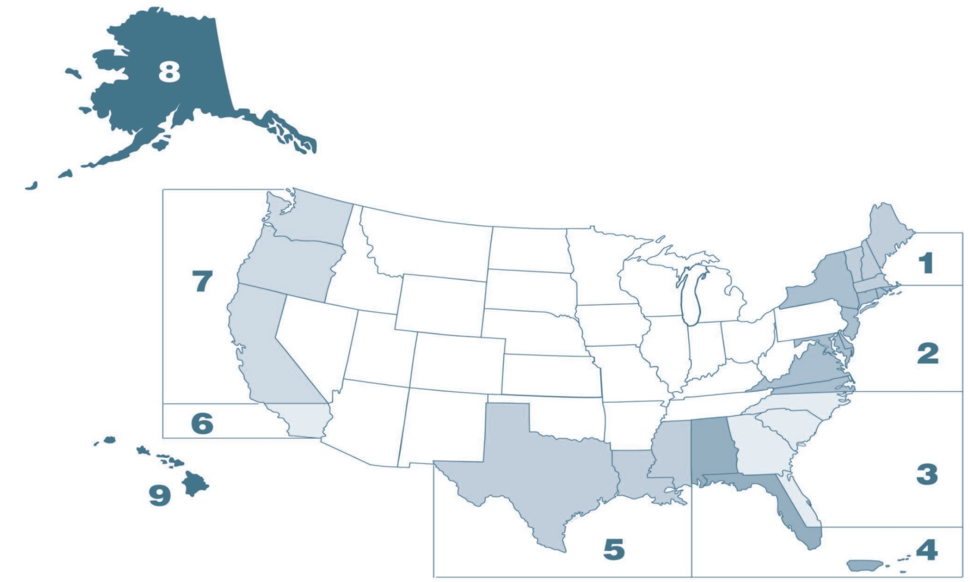
The NMDMP began with the establishment of 40 randomly selected marine debris monitoring sites along the Gulf of Mexico in 1996. Over the past four years, the NMDMP has expanded its coverage to over 130 sites located along the East, West, and Gulf Coasts including Alaska, Hawai'i, Puerto Rico and the U.S. Virgin Islands. The protocol for the NMDMP calls for 180 marine debris monitoring sites to be set up along the coastal U.S. and monitored by hundreds of trained volunteers coordinated by CMC.

METHODOLOGY

The U.S. coastline has been divided into nine regions (figure 3) based on available information on the types of marine debris found there and the prevailing currents. Twenty marine debris monitoring sites per region are randomly selected from a comprehensive list of beaches, which fit the NMDMP criteria. Each beach must be of low to moderate slope, composed of sand to small gravel, have a length of at least 500 m (1/3 mile), have clear direct access to the sea (not blocked by breakwaters or jetties) and must be accessible to volunteers year-round. Care is also taken to select beach sites that will not impact any endangered or protected species such as sea turtles, sea birds, marine mammals, and sensitive beach vegetation. At each designated study site, trained volunteers conduct beach cleanups and marine debris surveys every 28 days.

Figure 3

NMDMP Survey Regions



Region 1: U.S./Canada border to Provincetown, MA
Region 2: South of Cape Cod, MA to Beaufort, NC
Region 3: Morehead City, NC to Port Everglades, FL
Region 4: Port Everglades, FL, Puerto Rico, and U.S. Virgin Islands to Gulf Shores, AL
Region 5: Dauphin Island, AL to U.S./Mexico border
Region 6: U.S./Mexico border to Point Conception, CA
Region 7: North of Point Conception, CA to U.S./Canada border
Region 8: Alaska (southern coast and Aleutian Islands)
Region 9: Hawaiian Islands

NMDMP DATA COLLECTION

Data are recorded on the NMDMP data card by the volunteer survey teams. Information is recorded on 30 specific debris indicator items grouped into three general categories of debris: (1) ocean-based, (2) land-based, and (3) general sources.

Ocean-Based Source Indicator Items: gloves, plastic sheets (1 meter), light bulbs/tubes, oil/gas containers (>1 quart), pipe-thread protectors, nets (5 meshes), traps/pots, fishing line, light sticks, rope (1 meter), salt bags, fish baskets, cruise line logo items, floats/buoys.

Land-Based Source Indicator Items: syringes, condoms, metal beverage cans, motor oil containers (1 quart), balloons, six-pack rings, straws, tampon applicators, cotton swabs.

General Source Indicator Items: plastic bags (<1 meter), plastic bags (1 meter), strapping bands (open), strapping bands (closed), plastic beverage bottles, plastic food bottles, plastic bleach/cleaner bottles, other plastic bottles.

The 30 specific items listed on the data card will provide the information needed to measure the changes and trends in the amount of debris appearing on the U.S. coastline. Additional items may also be tracked that are specific and meaningful to local regions (i.e., plastic mesh bait bags in New England, fluorescent light tubes in the Gulf of Mexico). The data, which are collected by each volunteer survey team, are sent back to the CMC's Atlantic Regional Office in Virginia Beach, Virginia where the data are added to our national database.

As with any scientific study, quality assurance (QA) is practiced to ensure that all data collected are reproducible and comparable. It is the responsibility of each monitoring site survey director to follow QA procedures during the survey set-up, volunteer training, and data collection. Throughout the course of each year of the study, survey directors are instructed to randomly select four dates on which to conduct a QA procedure. The QA procedure requires the survey director to follow behind volunteers taking note of any debris items that were overlooked. Collected debris is reinspected and a new data card is completed with "QA" labeled on top. The original data card and the QA data card are returned to CMC for a calculation of percent error.

The data from this study will be analyzed at the end of the five-year study and will yield a more in-depth understanding into the nature and trends of marine debris in the U.S. Data will be examined both on a national basis as well as regionally. The program is currently in the final stages of the establishment of marine debris monitoring sites and the training of volunteers. To date, over 130 marine debris monitoring sites have been established along the coastal U.S. The initial analysis will begin on a regional basis upon completion of the first five years of data collection. Final analysis on a national level will occur once all nine regions have been established and operating together for a five-year period. Once five years of data collection on a national level is complete, analysis will begin to examine trends in marine debris as well as an examination of the major sources of the debris.

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STEWARD OF THE OCEAN: NAVY POLLUTION PREVENTION AT SEA

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INTRODUCTION

I am pleased to have the opportunity to represent the U.S. Navy at this international conference on marine debris and I thank the Hawaiian Island Humpback Whale National Marine Sanctuary and the National Oceanic and Atmospheric Administration for inviting the Navy to this important gathering.

As the military service responsible for protecting our nation's access to the sea and access to our overseas trading partners and allies, it is natural that we should play a strong role in ensuring that man operates in harmony with our natural environment, the sea. The Navy is and should, by its nature, be a key partner in the efforts to reduce and recover marine debris, and it is our strong desire to continue to be part of the solution to this complex issue. We should set the example for others who use the sea—including the navies of other nations—in pollution prevention, elimination of harmful debris in the oceans, and assisting where we can in the cleanup of marine debris (including derelict fishing gear).

THE NAVY'S ROLE

Let me begin by explaining what my office does for the Navy. As the director of environmental protection, my mission is: to interpret environmental regulations; to ensure compliance and accomplishment of environmental planning and assessment of the impact of our operations; training and research-and-development programs; developing policy guidance for use by the Atlantic and Pacific Fleets; and working to ensure our operators are able to train the way they intend to fight, sustain fleet readiness, and remain in harmony with the environment. To be successful in addressing our many challenges, I have developed a comprehensive four-part strategy which applies equally to addressing pollution prevention, compliance, restoration projects, and natural resources conservation issues, and can have application for marine debris.

Elements of Strategy

- Complying with applicable laws/in place/enforceable consistent with what you're trying to do.
- Focusing technology and research programs to increase knowledge and understanding.
- Developing consistent policy, procedure, and methodology along with user-friendly tools for our operators to accomplish their tasks.
- Actively cooperating and engaging in strategies with regulators, public, NGOs, and Congress to enhance mutual knowledge and understanding of important issues.

PROTECTION AND PREVENTION

I would now like to discuss a little of what we are doing today to protect the ocean environment and avoid pollution from ships. Actually, the Navy has participated in the cleanup effort of derelict fishing gear, and to start, I'll give two quick examples.

Example #1

Right here in Hawai'i, Navy divers worked with the Coast Guard, NOAA, the Center for Marine Conservation, and state and county agencies in 1998 to clean up nearly 13,000 pounds of derelict fishing gear and other debris that had washed up on French Frigate Shoals. In the process, the Navy divers discovered seventeen green sea turtle hatchlings trapped on Tern Island. The divers removed debris and cleared a pathway for the turtles to the ocean, so they could begin searching for food, helping to ensure their survival.

Example #2

Last year in South Carolina, sailors from Naval Weapons Station Charleston collected approximately 1,500 pounds of derelict fishing debris from local waterways as part of their annual Beach/River Sweep. Other examples abound and I'll mention some later in my talk.

Technological Advancements

Looking at the larger scope of society's responsibilities as stewards of the ocean environment, of which Senator Inouye spoke, the U.S. Navy is fully committed. In the areas of marine debris control and pollution prevention, we have worked hard and continue to invest a great deal of effort. My topic focuses on the Navy's technological advancements in these areas.

An increased awareness among scientific and legislative communities, notably the Marine Mammal Commission and the National Marine Fisheries Service, led to collaboration among marine debris experts in the mid-1980s. By 1987, Annex V to MARPOL and the Marine Plastics Pollution Research and Control Act were passed into law. The Navy implemented a program to develop and retrofit solid waste handling technology for all of our vessels, and by the mid-'90s, common practices such as discharging plastics and other wastes were being eliminated.

We now go to great lengths and considerable expense to offload all wastes to shore reception facilities when in port anywhere in the world. When at sea we treat oily water to less than 15 parts per million, hold all plastics, and discharge only processed solid waste. Black water and gray water discharges are restricted by law and Navy regulations. To ensure that our sailors understand the laws, we provide training and give them effective, easy-to-use tools, such as this device. We call it a whiz wheel, and it covers all the restrictions on discharge at sea.

In years past, the Navy's and other service's strategy for diverting pollutants from the environment was an "end cap" solution. We would clean up contaminants generated by our ships and bases and look for a safe place to process and dispose of the waste. Although this effort improved our waste stream in the short term, in time we found that it wasn't enough. The cost of collecting the waste, shipping it to processing facilities, and actually disposing of it was very high. In addition to the obvious costs, there was no light at the end of the tunnel; our waste stream would continue to flow and we would have to continue to pay to deal with it.

With a huge investment in research, the Navy embraced a new, more effective strategy over the past several years. We now review our processes from beginning to end, finding opportunities to reduce and eliminate pollution throughout the entire life cycle of the equipment. These efforts have made it possible for us to keep the environment cleaner, reducing the need for regulator-initiated cleanup and creating the opportunity for payback through recycling avenues and greatly reduced purchase of raw materials and hazardous substances. In fact, the hazardous materials we do use are tracked from cradle to grave to ensure no contamination of the environment.

The Plastic Waste Processor

Heat compresses and melts plastics, including food-contaminated plastics, into a 20" stable disk for storage onboard until the plastic can be offloaded ashore. Result: zero plastics discharge into the sea. [Show plastic disk] This colorful disk, known officially as a compress melt unit (CMU) and unofficially as a "plastic pizza," contains bottles, bags and other plastic materials used aboard ship. While underway, our modern aircraft carriers can generate over 300 of these disks each day. We're partnering with industry to research ways that these disks can be recycled or used in the construction industry.

PRIME Program

To reduce the total amount of plastics in the supply system, the Navy also established the Plastics Removal In Marine Environments (PRIME) office in 1990, which has evaluated over 350,000 items used on Navy vessels with the aim of reducing or replacing items to eliminate plastic waste. These changes have resulted in the elimination of over 500,000 pounds of plastics previously taken on board Navy ships each year.

The Metal and Glass Shredder

Shreds and breaks up metal and glass, which can't be retained on board for recycling, into small pieces that are placed in a burlap bag and discharged at sea. Result: no floating debris. The burlap, metal, and glass sink rapidly to the bottom where the burlap dissolves and the metal and glass are slowly assimilated into their natural elements.

The Solid Waste Pulper

Grinds paper, cardboard, and food waste into a benign, biodegradable slurry that is discharged at sea. Studies have shown that the pulped material quickly assimilates into the environment and biodegrades.

WRAPS Program

The Navy established the Waste Reduction Afloat Protects the Sea (WRAPS) to reduce the amount of total solid waste brought on ships. The goal of WRAPS is to reduce the amount of cardboard, paper, and packing and shipping supplies and containers that accumulate onboard. WRAPS coordinates with vendors to reduce the amount of packaging accompanying supplies purchased by the Navy and is evaluating ongoing efforts to replace paper documents used on vessels with CD-ROMs and electronic form preparation.

Parallel Plate Oil Water Separators

Existing Navy ships are equipped with parallel plate oil water separators that meet current standards. Next generation oily waste treatment will meet even stricter performance criteria through the use of Navy-developed effluent polishers that use membrane ultrafiltration technology to produce a cleaner effluent.

To prevent damage to marine ecosystems by accidental oil spills, the Navy has many mechanisms in place, both ashore and at-sea, to prevent the accidental release of oil into the environment and to provide a rapid response and cleanup action in the event of a spill. In addition to the well-established compliance programs on the installation level, Department of Defense (DoD) is a member of the National Response Team (NRT) established under the National Contingency Plan. Navy is the DoD Executive Agent for the NRT and possesses one of the world's largest inventories of oil pollution response equipment with response capability available from a worldwide network of installations. In the event of large-scale oil spills from whatever source, trained operators, mechanics, and supervisory personnel deploy from U.S. response centers with the appropriate equipment. For example, Navy fleet skimmers collected half of the oil recovered from the Exxon Valdez spill in Alaska.

Collection and Holding Tanks

Our existing fleet has been outfitted with (sewage) collection and holding tanks. The tanks are sized to retain all sewage while transiting within three nautical miles of land. The tanks will also collect graywater in port for offload to shore reception facilities including pier sewers, trucks, or barges.

Many other pollution prevention initiatives were prototyped on USS Carl Vinson. I served as her Commanding Officer from October 1994 through January 1997. I'll briefly describe some of the P2 processes and technologies we pioneered for the Navy.

The Aqueous Parts Washer
A self-contained unit that cleans small precision parts without the use of hazardous solvents.

The Electronic Particle Counter
Effectively "scans" machine fluids to determine the need for replacement, rather than "changing the oil every 3,000 miles." It succeeded in reducing hazardous waste generation by 50%.

The Hydraulic Fluid Purifier
Filters water and debris out of used equipment fluids, eliminating the need to dispose of the waste fluid and reducing the requirement for purchasing new fluids.

For our new ships we are currently developing a new waste treatment system that will employ biological treatment in conjunction with membrane filtration. Lab tests are encouraging and we anticipate this technology will be available to support our new DD-21 destroyer program.

Ultimately, the Navy is planning to design and build environmentally sound ships from the keel up. These ships will have minimum use of hazardous material and will treat or destroy all wastes on board. The resulting independence from shore waste offload facilities should dramatically reduce costs at ports and ensure the minimum possible impact on the marine environment.

THE FUTURE — WHERE WE ARE HEADED AT SEA

So rather than resting on our laurels, we are aggressively looking towards the future for a more effective and environmentally sound manner to address the shipboard solid waste stream through the development of state of the art advanced solid waste incinerator technologies, initially for our large platform ships. The development of this new shipboard technology will improve our solid waste processing capability by enabling our ships to more efficiently dispose of solid waste while at the same time helping us steer towards the Navy's ultimate goal of a zero discharge ship.

Pertinent Navy Success Stories

The Navy's recycling and cleanup programs have been significant in reducing potential plastics and other debris from entering local waterways, and subsequently coastal and marine areas. At the same time, Navy participates in numerous coastal and river cleanups, which are often coordinated by our natural resources managers.

International Coastal Cleanup
In 1991, the Navy began participating in the International Coastal Cleanup, sponsored by the Center for Marine Conservation. Starting with a pilot effort in Texas and Virginia, the Navy expanded participation in the program to bases in Florida and California in 1992. Since then, it has expanded nationwide as a voluntary program with high public support. Similar cleanup efforts have included the St. Johns River cleanup by NAS Jacksonville and NAVSTA Mayport, "Save the Bay" cleanups by bases in Norfolk area, Patuxent River, Dahlgren, etc., and similar efforts in Puget Sound coordinated by NSB Bangor, NAS Whidbey Island, and other overseas activities as well.

U.S.S. MY SCHOOL Program
Another contribution by the Navy was the development of the U.S.S. MY SCHOOL curriculum for fourth through sixth-graders. The Assistant Secretary of the Navy (Installations and Environment) funded the Center for Marine Conservation to produce this curriculum in celebration of the 1992–1993 Year of the Gulf of Mexico. The curriculum promotes a hands-on science approach to learning about marine debris and how it affects the health and safety of the world's oceans and beaches. Using their imagination, children convert their school into a ship; the cafeteria becomes the ship's gallery and each day the classroom becomes a place to think about how to come up with real hands-on solutions to marine debris.

School Partnership Program
Under the Chief of Naval Operations Personal Excellence Program, the Naval Pacific Meteorology and Oceanography Center partnered with the Moanalua Intermediate School in Honolulu, Hawai'i to initiate a program to educate school children about the environment. The program included periodic beach cleanups, a week in the classroom teaching environmental sciences with a focus on marine debris, student production of a "public service announcement" on marine debris, and participation in the International Coastal Cleanup, "Get the Drift and Bag It Day."

MCB Hawai'i Helps Clean Up Ghost Nets
"Ghost nets" are a constant threat in Hawai'i's near-shore waters. Averaging 300 feet in length, they drift in and impact reefs in three significant ways:

1) Smother, entangle, and kill the coral.
2) Transport alien species from reef to reef.
3) Entangle other marine life, including protected species.

Since 1998, Marine Corps Base Hawai'i (MCBH) has worked with state and community volunteers to remove over 5,000 pounds of net debris each year in Kaneohe Bay alone. These cleanup activities are an annual Earth Day event.

CONCLUSION

As you might expect, we are very excited about the current accomplishment of and the opportunity for our pollution prevention technologies and other Navy initiatives to continue to preserve our oceans and the overall environment. As we continue our vital missions, we are committing dollars and resources to making sure these “clean and green”efforts continue and grow.

As our technological abilities to preserve the environment improve and evolve within the Navy, we are experiencing a cultural shift as well. The young sailors who work aboard our ships and our shore facilities today have an ingrained, special appreciation for the environment that my generation is just now coming to grips with. These men and women grew up with recycling in their home communities. They are familiar with terms like “sustainable agriculture” and “e-commerce” and the environmental advantages those approaches bring. They expect the products they use and the vehicles they drive to be environmentally friendly.

These young sailors represent a new generation of seafarers, raised in homes and educated in schools where they have learned to value and protect our environment. Great lessons to be learned by all generations.

I hope and believe that this new, prevailing attitude will help the Navy as we strive to be good stewards of the ocean and environment while performing our crucial job of defending this nation.

Thank you for the opportunity to address you today, and I hope I have provided some insight into the technological solutions and strategies the Navy is using to do its part in preserving the environment and helping to solve issues such as those discussed at this conference. Thank you.

PLASTICS AND THEIR IMPACTS IN THE MARINE ENVIRONMENT

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INTRODUCTION

I want to thank the organizers of this conference for providing me with the opportunity to address this gathering. My research specialty is polymer science and engineering, particularly the topic of plastics and the environment. I think it is important to closely monitor the impacts of introducing plastics in to the fragile marine ecosystem and to study the various technical mitigation strategies that are available to minimize any damage due to plastics in the world’s oceans. In this short presentation I plan to achieve two objectives. First, I want to discuss the factors responsible for the breakdown of plastics once they are introduced into the marine environment. Then, I want to consider the various technical options, particularly the technologies for biodegradable and photodegradable plastics that are available, to address the problem of plastics in the marine environment.

TYPES OF PLASTICS

Shown below in table 1 are the major classes of plastics commonly used in fishing gear application. As you know, fishing gear, accidentally lost or intentionally discarded, remain an important component of persistent marine debris. There are hundreds of different types of plastics and plastic compositions, but of this only about four or five types are commonly used in fishing gear. The table also includes the specific gravity of the plastic and as you see some, as indicated, are denser than seawater and will sink rather than float at sea. Out of these plastics it is the nylons and polyethylenes (and also some polypropelynes) that are used most in the construction of fishing gear. This is not surprising as these plastics have the unique combination of properties that make them best suited for the purpose. For instance, they have very good strength, good elasticity, and have low perceptibility in the water column and contribute to the high efficiency and catchability of the fishing gear.

With all these strengths, plastics as a class of material have a significant drawback from an environmental standpoint in that they biodegrade at an extremely slow rate compared to other organic materials. All organic materials, including plastics, do biodegrade, but they biodegrade at such a slow rate that they are of little practical consequence. This bioinertness of plastics is both a drawback and also an asset because the biggest shortcoming of the natural fiber fishing gear that we had a long time ago was that they were readily biodegradable! They weakened as they biodegraded over time and therefore could be used for only a limited duration. However, in cases of loss or abandonment of the natural fiber gear, the environmental consequences were limited as the gear biodegraded readily without posing significant ghost fishing, entanglement, or other hazards.

Table 1 **Types of Plastics Used in Fishing Gear Applications.**

Type	Density (g/cm3)*	Buoyancy	Gear type
Polyethylene	0.96	float	Trawls
Polypropylene	0.90	float	Trawls
Nylon 6 or 66	1.14	sink	Trawl sections, gill nets
Saran fiber	1.70	sink	Seine nets

***** *A nominal density is given. Each class of polymers display a range of densities.*

Figure 1 (not shown) is representative of the consequences of poor biodegradability of synthetic fishing gear. It shows skeletons of marine mammals entangled in a submerged section of netting, probably nylon gillnet. What are the factors that govern the breakdown of plastics in the ocean environment, or for that matter, in any environment? The primary factor is the solar actinic radiation, or the part of the solar spectrum that spans from about 290 nm to about 315 nm. This ultraviolet radiation, called UV-B radiation, readily photodegrades all plastics commonly used in fishing gear. However, the effectiveness of this factor depends on whether an efficient light-stabilizer is compounded into the plastic. Understandably, manufacturers routinely incorporate efficient light-stabilizers into most plastic products, certainly including fishing gear, in an effort to obtain long service lifetimes. Therefore, in practice, the solar UV radiation does not have that much effect in breaking down most plastic compositions exposed to sunlight. In addition to sunlight, the slow oxidation of the plastic, where oxygen in the air oxidizes the plastics slowly and facilitates the breakdown, can be a contributing factor. This process too is very slow and with some plastics can be comparable to the rate of biodegradation. Hydrolysis (or chemical breakdown by water) is available with certain and very special types of plastics. But these types of plastics are not used in the fishing industry. The conclusion here is that there are no effective reliable mechanisms to breakdown a well photstabilized plastic product in a reasonable time scale when exposed to the marine environment.

This leads to perhaps the most popular question posed to scientists working in this area—"How long will the plastics last at sea?" Typically, scientists respond to this question somewhat vaguely. The lifetime of a plastic material in the marine environment is quite variable and depends upon the intensity of the different factors contributing to the breakdown available at that location of interest. It depends, for instance, on the temperature of the water column, on the amount of solar UV-B insolation, the biotic potential of the environment, and more importantly on how one defines the "lifetime" of plastic at sea. The term can have different meanings. Does it mean how long does the material persist in a geometry (such as webbing) strong enough to cause entanglement? In

which case you have a certain time period within which the strength of the extensibility of the plastic is decreased and an animal caught in the plastic netting can free itself without any problem. Alternatively does it mean in a stricter environmental sense that total mineralization or total conversion of the plastic to carbon dioxide and water? The latter process will take hundreds of years because most plastics mineralize at extremely slow rates.

RECENT STUDIES

Research over the last decade has clearly established one important factor conclusively. Plastic exposed floating at sea at a given location tends to break down at a much slower rate compared to the same plastic material exposed outdoors on land at the same location. This is reported to be generally true for most plastics, except perhaps for Styrofoam. In the case of Styrofoam, the material does break down into smaller particles faster at sea than on land, perhaps because of the unusual expanded bead structure of the material. This experiment has been carried out in several locations with various types of plastic products including troll webbing, rope used in fishing, six-pack rings, and Styrofoam packaging.

There are two reasons that can explain this finding. The first is that plastics in contact with seawater undergo extensive fouling. Sunlight is often not able to reach the plastic surface partially covered with foulants, unlike with the sample on land. This shielding effect of foulants on floating plastics can reduce the rate of light-induced breakdown. But more importantly, the differences in the temperature of the material exposed floating in seawater and in air on land may also explain the difference in rates of breakdown. The temperature of a piece of plastic exposed to sunlight on land rises up because of the absorption of infrared light, in a process called "heat buildup". The temperature of the plastic can rise by as much as 20° centigrade higher than that of the ambient air. But when the same plastic is exposed in seawater, the plastic is maintained at the relatively lower temperature of seawater. As the rate of degradation reactions has a positive temperature coefficient, the samples exposed in water degrade at a slower late.

This was recently illustrated in an experiment of weathering plastics in the desert environment where two sets of polyethylene film samples were used. One was exposed in air and the other placed in an UV-transparent box that was air-conditioned and kept at 25° centigrade. The tensile extensibility is a particularly sensitive indicator of photodegradation for film samples and was used to monitor the degradation process over a period of 10 months. While the experiment is still ongoing, the data collected to date illustrates the dramatic effect of temperature on the degradation process. The sample exposed in air disintegrated within a few months while the sample maintained at lower temperatures maintained its integrity and had significant residual extensibility even after 10 months of exposure.

Latex rubber balloons are an important category of product in the marine environment. Promotional releases of balloons that descend into the sea pose a serious ingestion and/or entanglement hazard to marine animals. Based on the fairly rapid disintegration of balloons on exposure to sunlight in air, the expectation is that balloons do not pose a particularly significant problem. In an experiment we carried out in North Carolina we observed that balloons exposed floating in seawater deteriorated much slower than those exposed in air, and even after 12 months of exposure still retained their elasticity.

What technological control options are available to mitigate the problem, if any? I want to briefly discuss four different options here. We have photodegradable plastics and we have a category called biodegradable plastics, which is somewhat of a misnomer in that all plastics are invariably biodegradable. These refer to particular types of organic polymers that biodegrade at a much faster rate than regular plastics. Then we have on-board plastic waste management that can be practiced on fishing vessels as well as on naval vessels. Then finally you have education, because willful discharge of plastics in the ocean is really a behavioral problem and there are no technical options that will completely eliminate that.

PHOTODEGRADABLE PLASTICS

There are certain types of products with which photodegradable plastics work very well. I do not want to get into a chemical discussion of the structure and function of these materials because of the lack of time. However the structure of polyethylene, for instance, can be changed chemically during manufacture so that it absorbs UV-B radiation from sunlight and breaks down into a very brittle material in a fairly short period of time. As polyethylene is the most used commodity plastic, this is a very useful technology. A common product, such as a six-pack yoke, when discarded outdoors may last a fairly long period of time. If the same item were made of this modified, enhanced photodegradable polyethylene, it would deteriorate in sunlight in a faster time frame, minimizing the chances of entanglement hazards. This type of technology is also useful in litter reduction to improve aesthetic appeal of beach or even urban areas.

An important consideration, therefore, is if this technology will perform adequately under marine exposure conditions as well as it does under land exposure. A test procedure employing a floating rig in the Biscayne Bay in Miami, FL was used in an effort to answer this question (the experiment was subsequently repeated in Seattle, WA). Essentially, a set of plastic samples of interest, for instance sections of trawl webbing, were attached to the PVC pipes that made up the rig and were exposed to sunlight while the samples were floating in sea water. The mechanical properties of these materials were monitored weekly over a period of time. This exposure procedure is now an ASDM standard protocol [ASTM D54 37]. We studied two of the commercially available photodegradable polyethylenes and found that the rate of degradation of the samples accelerated considerably even when the samples were exposed floating in seawater. The advantage in terms of

preventing entanglement from at least the polyethylene products in marine environment will be significantly reduced by the use of this technology. We also found, as expected, the rate of deterioration was slower than that of the samples exposed in seawater, compared to those that were exposed in air.

For instance, an unstabilized polyethylene film material, such as a section of a thick plastic sheet, exposed outdoors in Miami, would gradually loose its tensile strength over a period of several months. Typically, the point of embrittlement (the level of degradation where the material has virtually no strength and breaks down into little small pieces on handling) was reached in about three to three-and-a-half months. The period is short because the material has no light-stabilizer in it. But if you were to expose the same sample floating in seawater at the same location, after three to four months no significant decrease in the strength can be found. The test results on tensile strength will be about the same as the unexposed samples. In repeating the same experiment with photodegradable materials we found that the samples exposed in both air and seawater photodegraded and lost strength much faster compared to the regular unstabilized polyethylene material. The point of embrittlement for the samples exposed in water was reached in four to five months of exposure. Samples exposed on land embrittled in several weeks under these exposure conditions. However it is important to recognize that while convincing studies of this nature have been carried out on samples of different plastics, no data is available for plastic fishing gear made out of photodegradable materials.

With fishing gear using this type of technology an important question is the nature of trade off between catchability of the gear and its degradability in the ocean. This issue has not been addressed in the literature. In the early-’90s we carried out some studies on the fouling of fishing gear in both Biscayne Bay and the Seattle, Washington area. We do not have the time to examine all the findings in detail, but an important possibility emerged from that study. The study included measurement of the density of fouled trawl web segments at different durations of floating exposure. Based on the data, we were able to surmise that a floating piece of fishing gear in the ocean would initially increase in density because of copious fouling. The density would be high enough for the material to be negatively buoyant. This is hardly surprising because of the high levels of fouling obtained at the locations where the tests were carried out. Upon submerging it to a level in the water column that is determined by the density, the algal fraction of the foulant colony is likely to die because of the lack of sunlight. The density could change again and become low enough for the sample to float again. This was postulated based on density data for samples exposed floating and submerged in seawater. Recent experimental observations by Murray Gregory are consistent with this notion. In relying on solar exposure to bring about faster degradation of derelict gear at sea, the possibility of foulant-induced sinking and subsequent, possibly intermittent, disruption of the exposure needs to be taken into account.

With controlled lifetime fishing gear that employed photodegradable technology, it would of course be crucial to keep it shielded from light when not in use. The technology allows one to build an approximate timer into the gear that would allow it to be exposed to some predetermined level of exposure to sunlight before enhanced degradation sets in. Typically the transitions in strength of the gear, once the enhanced degradation has commenced, would be fairly rapid. At least in theory, it is possible to set this timer for controlled lifetime at a pre-selected duration of use longer than the anticipated period of use for the gear. This would not work for all gear, it would only work for floating gear, floating plastics, and for gear that is expected to last for a certain fixed period of time (not for gear that is continuously repaired and reused).

In these discussions we have assumed embrittlement to be an adequate end point in the degradation process. From the point of view of minimizing entanglement of marine mammals and perhaps ghost fishing, it is certainly a very pertinent end point. At embrittlement we have essentially converted the plastic six-pack ring, or a piece of netting, from a hazard into a collection of relatively small pieces. But have we removed the plastic material from the marine environment? In a recent experiment we exposed an enhanced photodegradable polyethylene sheet (the same material used in photodegradable six-pack rings) in Florida. The tensile strength was measured every few weeks to monitor the degradation of the sample. In addition, the molecular weight of the same samples used for tensile testing was measured using gel permeation chromatography (GPC). The goal was to find if the dramatic reduction in the strength of the photodegradable plastics was accompanied by a correspondingly large reduction in the molecular weight. At embrittlement, the molecule weight was 11,000! (see table 1) The material still remained a polymer. It is well established in the literature that a molecule rate of 11,000 polyethylene is not biodegraded in any practical time scale. There is no mechanism for biodegradation of that long of a molecule in the marine environment. In defining degradation in terms of embrittlement we may be helping the marine mammal population. The powdery residue, however, remains persistent in the sea environment as debris perhaps affecting the filter feeders. Some evidence of accumulation of small plastic pieces in the ocean environment has appeared in the literature.

A related issue is that of careless handling of virgin resin beads during transport and processing. Plastic resin beads are widely distributed in the world's oceans and are ingested by marine birds. This is an example of a type of plastic pollution for which there is no technological solution. What is needed here is better shipboard management and an increased general awareness of the fragility of the ocean ecology by all users of the sea. If one stops to think of it, except for the small amount of plastics incinerated, every little bit of plastic manufactured in the world for the last 50 years or so, still remains in the environment somewhere. It's either in the landfill or it's somewhere in the ocean because there is no effective mechanism to readily break it down.

BIODEGRADABLE PLASTICS

While most plastics biodegrade far too slowly to be practically significant, a few have chemical structures that allow rapid biodegradation. These are relatively expensive specialty plastics, rarely used in common applications. Some of the more promising polymers in this category are polylactic acid and poly (hydroxy butyrate valerate) copolymers. In biodegradation, microbial enzyme action converts a plastic material first into small organic molecules and invariably into carbon dioxide and water. This is the ultimate fate of natural materials such as plant and animal debris in the marine environment. The enhanced biodegradable polymers are generally more expensive than the common polymers such as polyethylene and nylon used in fishing gear. Also the effectiveness of the biodegradable plastics as materials of design for fishing gear has not been well studied. Materials for gear application require specific properties. Good elongation is important in gill net applications and good abrasion resistance as well as fast sinking rates are desirable in troll or bottom type gear. Nylons remain the most popular choice for construction of fishing gear because this class of plastics exhibits nearly all of these key properties (except perhaps for sinking speed where polyesters are superior).

CONCLUSION

While we continue to gain an increasingly better understanding of the fate of plastics in the marine environment, there are no ready-to-apply technical solutions to the problem of marine plastic pollution. Degradable plastics technology may eventually mature into a class of controlled lifetime fishing gear. But much developmental work needs to be undertaken to make this a reality. Other practical options include incentives to encourage the return of waste gear to the shore where collection facilities hold the gear for subsequent recycling. The reduction of shipboard plastics material is also a valuable contribution in this regard. The previous speaker had very elegantly described the Naval efforts in this regard. It is important to continue our efforts in education aimed at increasing the environmental awareness of users of the ocean.

Land-based plastic debris is a significant source of the plastic waste found in the oceans. The photodegradable plastics technology, already used in some products such as six-pack rings, has a valuable role in reducing beach plastic debris. Biodegradable plastics may also be appropriate for some of the products often found in beach debris.

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